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THE HUMBOLDT LIBRARY OF SCIENCE

ELECTRICITY

THE SCIENCE OF THE NINETEENTH CENTURY

BY

E. M. CAILLARD

PART I. (ILLUSTRATED)

NEW YORK
HUMBOLDT PUBLISHING COMPANY
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ELECTRICITY

THE SCIENCE OF THE NINETEENTH CENTURY.

A SKETCH FOR GENERAL READERS.

BY

E. M. CAILLARD,

AUTHOR OF "THE INVISIBLE POWERS OF NATURE."

WITH ILLUSTRATIONS.

NEW YORK:

THE HUMBOLDT PUBLISHING CO.,

28 LAFAYETTE PLACE.

PREFACE.

THE aim which the writer has proposed to herself in the present little work, is to give such an outline of modern electrical science as may be readily understood by readers who have no previous acquaintance with the subject, and who, though unable to make a serious study of it, wish to acquire sufficient knowledge to enable them to follow with intelligent interest the marvelous and rapid progress which is being made in this ever-widening field. That a science so comprehensive as that of electricity should be exhaustively dealt with in a sketch for general readers, is out of the question, even though the task had fallen to a far more competent pen than that of the writer. Nevertheless, a sketch sometimes answers a very useful purpose, in awakening a keen desire for a closer and fuller acquaintance with the truths of which it gives an indication. Should this be the case in the presence instance, the writer would be abundantly rewarded for what has been throughout a labour of love. At any rate most persons will agree with her, that to have no knowledge whatever of the striking advances which are being made in all branches of physical science, and especially in those which fall within the scope of "Electricity," is a considerable intellectual loss. It is even more than this, for there is no aid to faith in the Invisible greater than the pursuit of knowledge, which is for ever obliged to penetrate beyond the apparent in order to keep in touch with the real.

In conlusion, the writer desires to express the deep obligation under which she lies to Professor Ayrton, for most valuable assistance in the revision of the proofs, without which she feels that her work would have far less right to be regarded with confidence than she trusts is now the case. She has also to acknowledge the courtesy of Professor Silvanus Thompson and his publishers, in allowing her the use of several illustrations (Figs. 11, 12, 13 and 14) from his work, "Elementary Lessons in Electricity and Magnetism;" and of Messrs. Siemens Brothers; Lang, Wharton and Down; and Batley and Greenwood, for the illustrations of dynamos, etc., in Part IV.

EMMA MARIE CAILLARD.

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STATIC ELECTRICITY

OR

ELECTRICITY AT REST.

PART I.

CHAPTER I.

ELEMENTARY PHENOMENA.

Definition of Static Electricity—Electrical attraction—Known to the ancients as a property of amber—Gilbert's discoveries—Electrical repulsion—Two opposite states of electrification—Explanation of the terms vitreous and resinous—Superseded by positive and negative—Franklin's theory—Idea of excess and defect acknowledged in modern science—Proofs of its correctness—Analogy between the present state of knowledge of positive and negative electricity and the pre-scientific knowledge of heat and cold—Conductors and non-conductors—Meaning of charge and discharge—Induction—Action of points.

UNDER the head of *Static Electricity* are classed those phenomena which are not caused by a continuous flow or "current" of electricity; and though they were the earliest known, and are frequently considered as appertaining more or less to elementary knowledge, they yield neither in interest nor importance to the other branches of the science. Of late, special attention has been devoted to them by various scientific experimenters, as modern research leads to the opinion that here, if anywhere, will be found the ultimate solution of some of the many vexed questions surrounding that ever-recurring inquiry, "What is electricity?" Moreover, the eminently practical and useful study of atmospheric electricity belongs chiefly to this branch of the science, which cannot therefore be considered as either barren or uninteresting.

The first electrical phenomenon which claims our attention is that of attraction. Through the whole domain of Nature we are familiar with attraction under one form or another. There is the attraction of the members of the solar system for each other and for their great centre; the attraction between the earth and all terrestrial objects; the attraction between particles (or molecules) of matter, which enables them to form into the larger and smaller masses which we call bodies; lastly, there is the attraction between the elementary chemical atoms leading them to combine and re-combine in an endless variety of ways, thus producing all the different substances with which we are acquainted. And now on the threshold of this latest developed science we are confronted with the phenomenon of attraction again, in a new form and under different conditions certainly, but an old friend nevertheless.

It is supposed that Thales, one of the seven sages of Greece, was the first to discover that amber when rubbed acquired the power of attracting small light bodies to itself. Be this as it may, the fact was known to his countrymen hundreds of years before the Christian era; and to the Greek word "electron," amber, is due the name electricity.

Two thousand years passed away, and, save that jet was found to share the same property as amber, no further advance was made in electrical knowledge. Then, in the reign of Elizabeth, so fruitful in progress of all descriptions, Dr. Gilbert, of Colchester, whom the Queen had appointed her physician chiefly out of admiration for his acquirements in natural science, added several facts to the one which had so long held the field alone. He found that glass, rock-crystal, gems, sulphur, resin, and various other substances developed on friction the same power of attraction as amber and jet. He called these electrics. Metals and such substances as appeared devoid of any attractive property he termed non-electrics. Gilbert was wrong in this classification, however; for, under suitable conditions, to be presently described, all substances behave as electrics. Gilbert also ascertained that moisture prevented the success of his experiments, and that an electrified body, if set on fire, passed through a flame, or made very hot, lost all sign of electricity.

It is easy to reproduce Gilbert's experiments on electrical attraction. A rod or tube of glass held in the hand and rubbed with a silk cloth will powerfully attract small pieces of paper, pith, or other light bodies, just as a magnet will attract steel filings or needles; with the difference, however, that whereas in the magnet the force of attraction seems to lie in the two ends, in the rubbed glass it exists all over the surface, so that the pieces of paper will adhere to it anywhere.

Electrified objects possess a force of repulsion as well as of attraction; for, in making the above experiment, it will be noticed that in a very short time the pieces of paper or pith fall off the glass, and will not

at once be attracted to it again. If, however, while they are in a state of repulsion toward the glass, a stick of rubbed sealing-wax be approached, they immediately fly toward and adhere to that, to be again soon repelled, when the glass will be once more found able to attract them. These phenomena point to the conclusion that bodies can be electrified in two ways, and that those electrified in the same way repel, while those electrified in opposite ways attract each other.[1] A still more striking proof is afforded by the fact that a couple of rubbed glass rods suspended by silk threads repel each other, and so do two rubbed sticks of sealing-wax, but the glass attracts the sealing-wax and the sealing-wax the glass.

These opposite kinds of electricity were at first called *vitreous* and *resinous*, because it was believed that "vitreous" substances always gave signs of one kind of electricity and "resinous" of the other. This is a mistake, however. Glass rubbed with silk becomes "vitreously" electrified, but rubbed by fur becomes "resinously" electrified. It is evident, therefore, that the kind of electricity manifested depends on some relationship between the rubber and the object rubbed; and it is now supposed that the substance whose molecules are least disturbed by friction shows "vitreous" electricity, and the one where they are most disturbed "resinous." These terms vitreous and resinous have, however, quite fallen into disuse, and are replaced by *positive* and *negative*, known in technical works by the signs + and —. The American philosopher, Franklin, was the first to introduce them, as he was also the first to formulate a theory justifying their use. He supposed that electricity was an invisible and imponderable fluid, existing in a certain fixed quantity in all bodies in a natural state, and that the positive state of electrification showed an excess, and the negative state a defect of this fluid. Whether electricity be or be not a fluid,[2] it is now agreed that it is equally distributed in all bodies which are in a natural state, and that the idea of excess and defect does truly represent the conditions that occur in positive and negative electrification; which is actually the state of excess and which of defect not being, however, a matter of certainty. Practically, positively electrified bodies are considered and treated as those in which there is an excess of electricity.

[1] It has been proved that two small electrified bodies attract or repel each other with a force varying inversely as the square of the distance between them. This law is known as Coulomb's law, he having been the first to discover it.

[2] It is certainly not a fluid in the ordinary acceptation of the term; and in speaking of electricity at all as a separate entity, care must be taken to remember that this is done for convenience' sake. We speak of "electricity" as we might speak of a gale or a whirlwind. These have no existence apart from the air of which they are certain states or conditions, and in the same way the various electrical phenomena are caused by conditions not of the air, but of another medium, to which further reference will be made hereafter.

One proof of the truth of this theory of excess and defect lies in the fact that it is impossible to produce a manifestation of one kind of electricity without causing an equal quantity of the other to appear also. A rubbed glass rod becomes positively electrified, but the silk which rubs it becomes negatively electrified, as can be seen by using it fastened to a glass handle instead of holding it in the fingers. After friction it will be found that both the glass rod and the silk will attract small neutral bodies, and that when these are respectively repelled, those repelled by the glass will be attracted by the silk and *vice versa*.

Many persons seem to find a difficulty in these terms positive and negative, asserting that it is impossible to attach a definite meaning to them, as they convey no clear idea to the mind. There is no doubt, indeed, that if scientific men really knew what positive and negative electricity are they would be able to find better names for them. In the meanwhile, as the idea which is wanted to be conveyed is that the two electricities are of opposite kinds, perhaps the terms positive and negative are as good as any that could be put forward. One is almost afraid in the present state of knowledge of venturing the analogy, but possibly the experience which has been gone through in the case of heat and cold may aid the conception of some readers. Cold is the opposite of heat; we now know that it is merely a negation, the absence of heat; people did not always know this. They supposed that cold was a thing in itself, but this error did not prevent their having a very clear practical conception of what cold was, and of knowing what they must do to neutralize it—produce heat. In the case of electricity the converse of this experience is taking place. We say positive and negative electricity are opposite, and it has been assumed that the positive is the thing in itself, and the negative, the negation, the want of this thing. But this is not true; negative electricity is as real as positive, though no one can pronounce what either is. Pending further discoveries, however, we may have, and electricians have, quite as good a working conception of positive and negative electricity as the generality of mankind had of heat and cold before science had discovered what these really were. Moreover, it is perfectly understood what must be done to neutralize one kind of electricity—produce the other.

It will have been observed that a silk thread was recommended for suspending the glass and sealing-wax in one of the experiments above described, and that in order to discover the electrical state of the rubber it must not be handled in use, but fixed to a glass stem. The reason is that some substances are conductors, and some non-conductors of electricity. An electrified body placed in contact with the former at once parts with its surplus electricity to them, or, if it be in a state of defect, receives from them the electricity needful to restore it to a natural state. Non-conductors, on the contrary, do not allow

of the free passage of electricity to and from them in this way, and consequently an electrified body, in contact with them only, cannot return to its normal condition until it has been touched by a conductor. To this latter class belong all metals, impure water and charcoal. Animal bodies, dry wood, and a few other substances are partial conductors. Oils, silk, porcelain, dry air, and all the so-called "electrics" are non-conductors or *insulators*, thus named because an electrified body surrounded by them is insulated, so far as its electrical condition can be affected by conduction, from every other object; and any body, no matter how good a conductor it may be, will in such a position become an "electric." It is for this reason that Gilbert's division of bodies into "electrics" and "non-electrics" was erroneous. Had he fastened a piece of metal to a clean, dry glass support, and touched it with an electrified body, he would have found the metal acquire the same property of attraction as amber or rock-crystal; for conductors need nothing more than contact at one point with electrified bodies to become electrified themselves over their whole surface. In the case of non-conductors, on the contrary, every part of the surface must be separately touched and excited. It is for this reason that friction is necessary in their case, and it will be the more effectual the more markedly different is the electricity which they develop; for there are stages in this respect, some substances being relatively to each other much more decidedly positive and much more decidedly negative than others.

A body in an electrified state is said to be "charged," and it is "discharged" when it returns to its natural condition. At the moment of discharge a crackling noise is often heard, and, if in the dark, small sparks may be seen. The rubbing of a cat's back with the hand will produce these, and also, in certain dry states of the atmosphere, combing the hair. Conductors are instantaneously discharged if touched by the hand, or by any object in connection with the earth (*i. e.*, in electrical connection by conductors, or partial conductors, such as the floor and walls of a house, for instance); but in the case of a "highly" charged body, it is not always safe to use the hand as a discharger, for the passage of electricity through a living body produces curious and strongly marked physiological effects, and in some instances the disturbance may be so great as to occasion loss of consciousness, and even of life, as when a person is "struck" by lightning. It is hardly necessary to observe, however, that to produce such phenomena as these an apparatus very different from rods of glass and sealing-wax is required; and, in fact, for any but the most elementary experiments an electrical machine is needed. Before entering into any details on this subject, however, some description must be given of what is called *electrical induction*.

An electrified body brought near a conductor has the pow

causing the latter to become electrified also, but in the opposite way to itself. Thus, if the former be positively charged, the latter will become negatively charged ; and although, if uninsulated, it would be incapable under ordinary circumstances of retaining the electrified state, in the present instance it will do so, as long as it remains in the neighborhood of the influencing conductor. Such a charge as this is called an *induced charge*, and electricity under such conditions is said to be *bound*, because the close proximity of a charge of the opposite nature prevents it from availing itself of the open way of escape to the earth, which it would otherwise immediately take. If both the conductors are insulated, the effect produced is different. Suppose the inducing charge to be positive as before, it cannot now give rise to an induced charge which is wholly negative, because there is no means of escape for the positive electricity contained in the conductor which is being influenced. The negative electricity of the latter is therefore attracted to the end nearest the positively charged conductor, and the positive electricity is repelled to the farther end, so that the two ends are electrified in opposite ways, while the middle appears to be in its normal condition (see Fig. 1). Could the conductor be divided in two—an arrangement often made to exhibit this phenomenon—that half of it which had been nearest the positively electrified body would be found negatively charged, and that which had been farthest from it, positively charged. Charge by induction differs from that by conduction, therefore, in the fact that the former can be caused by altering the distribution of electricity, while the latter requires an alteration of quantity. For instance, if an uncharged insulated conductor were brought near a positively charged insulated body (as in Fig. 1), no electricity would be put into or taken out of the former ; so that if its power of acquiring a charge depended only on an alteration of the quantity of electricity possessed by it, it could not under these circumstances be charged at all. Yet, as a fact, a conductor thus placed does become charged, one end (or side, if it be an upright bar or sheet of metal) positively, and the other negatively. If the influencing body be taken away, the conductor will return to its natural electrical state ; but if the former be left, and the latter connected to earth, the conductor will become, as we have seen, negatively charged ; and if it be then insulated again, and the positively charged body removed, it

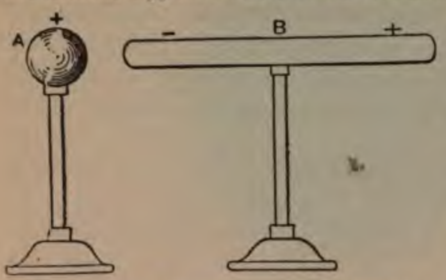

FIG. 1.—Diagram illustrating the charge induced in an insulated conductor B, by the neighborhood of a positively electrified body A.

will retain its negative charge, because now an alteration has taken place in the quantity of electricity it possesses, some having escaped to the earth, and therefore while insulated it cannot return to its natural condition.

We have hitherto been considering the inducing and induced charges as separated by a thickness of air great enough to form an insurmountable barrier to their union. Suppose the two bodies to be approached nearer to each other, this barrier may become too slight to resist the strain which is going on; and, just as the pressure of water on a dam may burst the dam, so the accumulated electric pressure bursts the insulating medium, a spark and report take place, and the two bodies are discharged. The subject of induced charges and the phenomena connected with them is full of interest, and will be referred to at greater length in Chapter IV. Meanwhile, before entering on a description of electrical machines, another fact of great importance must be stated, viz., the action of points on electricity. Franklin was the first to discover this, and he found that their effect is twofold. A pointed conductor both collects a far greater quantity of electricity than one with a flat or rounded surface, and the discharge from it is also much more rapid and powerful.

CHAPTER II.

ELECTRICAL MACHINES AND THEIR EFFECTS.

General principles of electrical machines—Von Guericke's machine—Cylinder and plate machines—Use of points in electrical machines—Experiments with electrical machines—Electric chimes—Electric windmill—Luminous effects—Electric spark—Brush discharge—St. Elmo's fire—Electrical glow—Discharge through rarefied air and gases—Return shock—Production of ozone—Difference between frictional and influence machines—The electrophorus.

AN electrical machine must always consist of two principal parts, one for producing and the other for collecting electricity; and in *frictional machines* the quantity of electricity brought into play depends on three things—the extent of surface subjected to friction, the amount of friction used, and the nature of the two substances brought into contact. These should always be chosen so that the one should be the most positive and the other the most negative possible, relatively to each other. The first frictional machine was invented by a German, Otto von Guericke, in 1680, and consisted of a large sulphur ball, supplied with a wooden axle, and mounted on a frame. The hand was used as a rubber; and with this simple contrivance

Von Guericke succeeded in producing much more powerful effects than had ever been obtained before.

The modern frictional machine is, however, very far superior to this. The surface to be rubbed usually consists of a large glass cylinder or plate, provided with a handle by which it can be turned, and the rubber of a leather cushion or cushions, coated with a powdered amalgam of zinc or tin. In front of the glass, but not touching it, is placed the "prime conductor," which must, of course, be insulated. It consists in the case of the "cylinder machine" (Fig. 2) of a thick bar of metal, either solid or hollow, placed on glass supports, and provided with a row of small metal spikes at the end nearest the glass cylinder; and in the case of the plate machine, of two bars similarly armed, or of one bent round so that both its ends should be presented to the flat surface of the glass, or else of a large metallic ball, on which a smaller one is often placed. When the handle is turned, positive electricity appears on the glass and negative on the rubbers, which are generally provided with a metal chain, con-

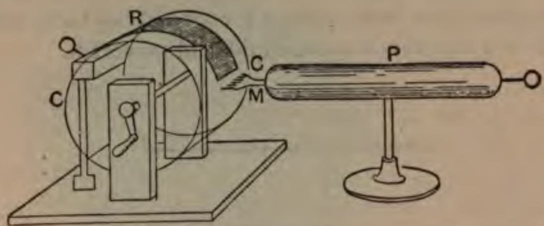

Fig. 2—Cylinder Frictional Machine. C C, glass cylinder; R, rubber; P, prime conductor; M, metal comb.

necting them to "earth" through the floor and walls of the building. The positive charge on the glass induces a negative charge on the nearest end of the prime conductor, whose positive electricity is repelled to the farther end, and is in fact the charge used for the experiments required. The metal points discharge the negative electricity at the near end, in a powerful stream, on that part of the glass plate which is opposite to them for the moment, and which consequently returns to the rubbers as the plate continues to revolve, unelectrified and ready to be excited again. This is an important part of the arrangement, because bodies cannot receive an unlimited amount of electricity. When charged up to a certain degree (which varies according to the shape, size, and position of the body), they cannot be further electrified until discharge has taken place; and the glass plate of the frictional machine would reach its highest effective point, and be incapable of further strengthening the induced charge on the prime conductor, in a very short time, if it were not for the action of the points above described. As the machine is provided

with these, however, the induced positive charge at the far end of the conductor becomes very powerful, and long sparks can be drawn from it by presenting another conductor, and experiments performed to demonstrate various electrical phenomena. One sometimes made use of to illustrate attraction and repulsion is the production of "electric chimes," first invented by Franklin. Three bells are hung from the prime conductor, the two outer ones by wires, the inner one by a silk thread, and having attached to it a metal chain connected with the ground. Two brass balls hung by silk strings are placed between the bells, which being positively electrified through their connection with the prime conductor, attract them, and are struck by the balls. The latter becoming immediately charged with the same electricity, are repelled and attracted toward the uninsulated central bell, against which they strike and discharge themselves, when the outer bells again attract them. Thus they go on alternately charging and discharging themselves, and causing thereby the musical "electric chimes."

Another experiment often shown is the electric windmill, which illustrates the action of points. It consists of straws or very light metal wires placed crossways and supported on a pivot, with the pointed ends all bent at right angles in the same direction. The whole arrangement is then fixed on the prime conductor of an electrical machine, and becomes strongly electrified, the greatest quantity of electricity collecting at the points, from which it streams off, causing, by the repulsion of the air-particles which it electrifies, a current of air known as an electrical "whirl." The effect of this is to drive the windmill rapidly round in the opposite direction to that of the points. Such a current is often strong enough to blow out the flame of a candle, and can always be felt by placing the hand in its path.

Beside demonstrating very strikingly electric attraction and repulsion, the action of points, and various other interesting phenomena, electrical machines can also produce luminous effects, which are simply reproductions on a small scale of the grand and beautiful natural appearances caused equally by electricity. The electric spark has already been mentioned, and it is simply a miniature flash of lightning; the very shape of the one, with its sinuous and branching appearance, irresistibly recalling the other, even to the most cursory observation. The electric spark is vivid enough to be seen in broad daylight, but an equally beautiful though less brilliant effect is the brush discharge, which requires a darkened room in order to be made visible. It is caused by a continuous flow of electricity from some conducting body. To facilitate this from an electrical machine, a piece of wire filed at one end is attached to the prime conductor, or, if the latter be highly charged, a bullet will answer the purpose. A

fan-like brush of light, whose pointed end rests on the piece of wire or bullet, is then seen, varying in strength according to the nature and amount of charge of the conductor, and being always larger and brighter when the latter is positively than when it is negatively charged. The brush discharge is usually accompanied by a continuous hissing noise, very different from the sharp crack of the spark; but if the conductor be pointed the discharge takes place silently, and is attended by a pale-blue light, called an "electrical glow," which becomes a small bright star if occasioned by negative electricity. "St. Elmo's fire," often seen by sailors on the masts of their ships, is an example of glow discharge. It is also sometimes observed on trees, and more frequently on spears and lanceheads, or on the points of bayonets. Such appearances only occur when the atmospheric electricity is in a very disturbed state, most frequently before and during storms.

The usual appearance of the electric spark is, as has already been stated, that of a miniature flash of lightning; but if it is made to pass through a tube in which the air has been rarefied, a great change takes place. The light assumes a violet tint, and spreads out so as to fill the whole tube, if the latter be not too wide, flickering in such a way as to suggest the idea of undulations traveling in the same direction as the positive electricity. "Geissler's tubes" are generally used for making experiments of this kind. They are simply thin glass tubes, blown into the required shapes and partially exhausted of air; into each end is fused a piece of platinum wire, by means of which the spark is conducted into the tube. Very interesting and beautiful effects are produced by these means. It is found that at the positive pole there is usually a single small bright star of light, while the negative pole is surrounded by a blue or violet-tinted glow, separated from the pole, however, by a small dark space. The more the air is rarefied the paler does the luminous discharge become, and if exhaustion is carried to a sufficiently high pitch the whole tube becomes dark. The darkness appears to proceed from the negative pole, as with every increasing stage of exhaustion the dark space between it and the glow of light grows wider. Sometimes all the light in the tube breaks up into successive patches or *striæ*, as they are called, which vibrate to and fro. These striæ have their origin at the positive pole, and commence at a certain pitch of exhaustion, increasing in number as this increases for some time, when if the air or gas be still further rarefied they grow fewer and thicker. The color of this luminous discharge is found to vary with the kind of gas through which it passes, and also with the nature of the metallic conductors forming the opposite poles. The former cause is most active when the discharge is weak, and the latter when it is powerful. To observe the color it is best to use narrow tubes. The light is seen to be of a

violet tint in air and oxygen, blue in nitrogen, red in hydrogen, and white in carbonic acid.[1]

The effect produced by the metal conductors on the color of the luminous discharge seems to be due to the vaporization of small particles, owing to the intense heat developed at the respective poles, and, indeed, along the whole passage of the spark. This heat is so great that fine wires may be made red hot and even fused by it, presenting an analogy to what sometimes occurs in the case of lightning and lightning conductors. The latter, especially in former days, when their proper construction was less well understood, have not infrequently been melted by a violent discharge.

Persons standing near a powerful electrical machine at work often experience a curious sensation, as though a cobweb were spread over the face, and when it is discharged they perhaps feel a "shock;" this is the same thing as what is known as the "return shock" in the case of a lightning flash, and is caused by induction.[2] In both cases the presence of a charged body (be it cloud or electrical machine) causes a charge of opposite sign in other bodies near it, and when it is discharged they also discharge themselves, and in the case of a living being a "shock" is felt. There is also invariably a peculiar and powerful odor in the neighborhood of an electrical machine in action, due to the presence in large quantities of ozone, which is a modified and, so to speak, condensed form of oxygen, and to which further reference will be made in a future chapter.

The machines of which a slight description has been given above, though partly owing their efficiency to induction, are known by the name of frictional machines, since it is friction which generates and keeps up the supply of electricity. There are, however, other machines much more powerful, and greatly used in laboratory experiments, which are wholly dependent on induction; and just as the parent of the perfected frictional machines of modern days was the homely apparatus of Otto von Guericke, so the progenitor of the powerful "influence" machines is the simple, and, to all students of electricity, familiar little instrument known as the *electrophorus.*

As its name indicates, it is a contrivance for carrying electrical charges from one place to another. It consists of three parts, two metal discs or plates, one of which is provided with a glass handle, and a slab of resin or ebonite—usually the latter in modern instruments—which fits into the lower plate (see Fig. 3). The ebonite is electrified by friction with wool or fur, its charge being, of course, negative. The upper metal disc is then placed upon it, but does not

[1] Sparks from induction coils are more frequently used in these experiments than those from electrical machines. See p. 97.

[2] It appears, however, that other causes may be at work [illegible] return shock. See p. 44, note.

actually touch more than three or four points of the surface, from which it is separated by a very thin film of air, so that it is really in the position of an insulated conductor in the close neighborhood of an electrified body, and becomes positively charged by induction, the negative electricity being repelled to the outer surface. The disc is then touched with the finger, or in some way momentariiy connected to earth (so that the negative electricity escapes), and being lifted away from the ebonite by means of the insulating handle, is found to have retained a positive charge powerful enough to permit a good-sized spark to be drawn from it, if another conductor be presented to its surface. As the disc was electrified by induction, no part of the original charge of the ebonite has been taken away, and the latter will be capable of recharging the disc an indefinite number of times without requiring to be again electrified itself. The simplest way of understanding the action of the

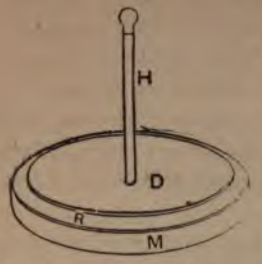

FIG. 3.—Electrophorus. M, lower metal plate; R, resin or ebonite disc; D, upper metal plate attached to H, insulating handle.

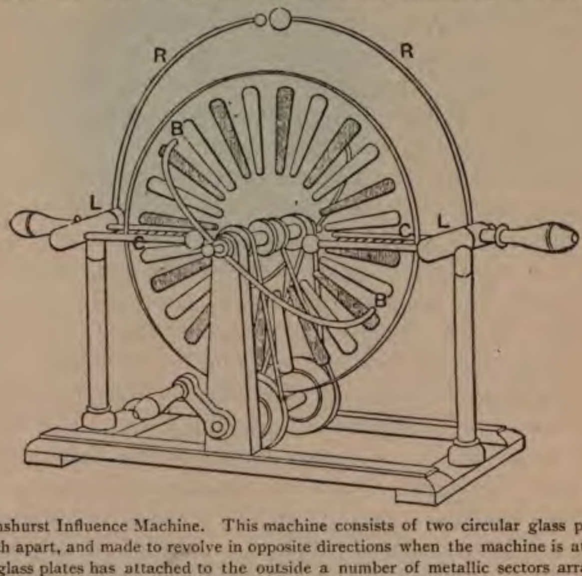

FIG. 4.—Wimshurst Influence Machine. This machine consists of two circular glass plates, about ⅛ of an inch apart, and made to revolve in opposite directions when the machine is at work. Each of these glass plates has attached to the outside a number of metallic sectors arranged like the spokes of a wheel. These sectors perform the office of both inductors and carriers, the carriers on one plate acting as inductors to the carriers on the opposite plate. The machine is provided with two discharging rods R R (whose knobs must be separated, and the rods themselves connected to the insulated brass cylinders L L, when the machine is to be used for charging any body), four collecting combs (two of which, C C, are seen in the figure), and two curved brass rods B B (one only represented), which carry at their ends small wire brushes connecting the pair of carriers which are at the moment under the influence of the inductors.

electrophorus is to bear in mind that when the ebonite has received its negative charge, and the metal plate attached to the glass handle

is placed upon it, both this plate and the one under the ebonite have positive charges induced on the surfaces facing the ebonite. Therefore, if either plate be connected to earth, and then insulated and removed, it will retain a positive charge (see p. 12). The charge thus communicated to the electrophorus can be conveyed to any conducting body and given up to it by contact, and if the process is repeated often enough an insulated conductor may thus become electrified to a high degree. In an ordinary electrophorus there is no way of giving rise to or increasing the original charge on the ebonite except by friction. In the accumulating influence machines, referred to above, however, which are made on the principle of the electrophorus, the initial charge is produced in quite a different way (explained on page 21), and is increased by a system of action and reaction, which enables influence machines to produce effects far exceeding in magnitude any to be obtained by the same amount of mechanical labor from frictional machines. The best known influence machines are the Holz and the Wimshurst. The latter is represented in Fig. 4, but its principle cannot be understood until the explanation respecting *potential*, and *difference of potential*, given in the ensuing chapter, has been read (p. 21).

CHAPTER III.

ELECTRICAL CHARGES—SOURCES OF ELECTRICITY OTHER THAN FRICTION.

Seat of "charge"—Biot's experiment—Faraday's experiment with conical bag—Proof-plane—Distribution of electricity on the surface of a sphere—On other surfaces—Density—Cause of charge—Analogy with dammed-up water—Importance of insulating medium—Capacity of bodies—Potential—Detection of charges—Gold leaf electroscope—Slightness of causes producing charge—Measurement of charges—Torsion balance—Coulomb's law—Electrometers—Difference between force and quantity—Various sources of electricity—Electricity not made but caused to manifest itself by disturbance of equilibrium—Analogy with air.

HITHERTO nothing has been said as to the seat of the charge in an electrified body, though the expressions used may have led to the true inference that it resides wholly on the surface. The interior of a conductor is never found to be electrified when electricity is at rest on it. The outer surface alone is capable of "charge."

This has been proved in a variety of ways. One experiment known as Biot's[1] is to electrify an insulated metal ball, over which two

[1] It was really first performed by Cavendish.

hemispheres, also made of metal and provided with glass handles, can be fitted. So long as the hemispheres do not touch the ball, it retains its electrified state, but the most momentary contact suffices to transfer the whole charge to the outer surface of the hemispheres, the ball being left without a trace of electricity. Another experiment, devised by Faraday, is to electrify a conical linen bag placed on an insulating stand, and provided with silk strings by which it can be turned inside out. When electrified, the charge is ascertained to be on the outside; the strings are then pulled, so that what was the inner becomes the outer surface, and the charge is again found to be on the outside, showing that the electricity must have passed from one surface to the other in order to retain its outside position.

A third way of proving the same fact is by means of a little instrument called the proof-plane. This is a very small metal disc or bead fastened to a glass stem, and which when placed in contact with an electrified body receives a small part of the charge. If this disc be carefully inserted in a hollow metal ball which has been electrified, and be made to touch the inner surface, no trace of electricity is communicated to it, but it becomes charged directly by momentary contact with the outer surface.

A sphere sufficiently far removed from other conductors to be practically outside the range of their influence, is the only body over whose surface electricity distributes itself with perfect equality. Bodies of any other shape will have more electricity on some parts of their surface than on others, and at every point or edge it will collect in greater quantities than anywhere else. The quantity of electricity per unit of area (*i. e.* per square centimetre), at any given spot on the surface of a body, is called the *density* of electricity at that spot; and wherever the greatest density is, there also will the greatest effort be made to escape, and there will the discharge, if there is one, take place.

The fact that charges reside only on the surface of bodies, points to the conclusion that the real seat of the effects produced is not after all the conductors, as was formerly supposed, but the insulating medium by which they are surrounded. If all bodies were perfectly conducting, there could be no possibility of disturbance in electrical equilibrium, because electricity could pass freely to and from all, thus finding its own equality of distribution, as water finds its own level. A "charge" occurs because at the surface of a conductor the electricity meets with a medium into which it cannot pass, and it as it were piles itself up so as to acquire strength to break through. Dammed-up water and an electric charge are much in the same situation. Both are unnaturally confined, both will escape from confinement if they possibly can; the water either by overflowing or bursting its banks, the electricity also by overflow, *i. e.*, leakage, or by discharge,

i. e., by suddenly bursting the imprisoning medium. Faraday was the first to point out that the study of the insulating medium was in fact of far greater importance than that of conductors; and since his time the attention of electricians has been much more turned in this direction, to the great benefit both of theoretical and practical knowledge.

It is evident that all electric charges cannot be alike; the same body may receive either a small or a large charge. Again, different bodies have what is called a different *capacity* for charge, *i. e.*, some are capable of accumulating a larger quantity of electricity than others. The capacity of a body depends partly on its size; the larger it is, *i. e.*, the greater extent of surface it possesses, the greater the quantity of electricity it can receive; but capacity is also affected by other causes, to be mentioned hereafter.

The electrical condition of a body compared with that of some other body or bodies is called its *potential*, and a charge may be one of either high or low potential. A small body receiving a certain amount of electricity may be at a high potential; a much larger body receiving the same amount of electricity would be at a low potential; and the tendency of electricity is always to flow from a body at high potential to one at low potential, so as to equalize its distribution, just as the tendency of water is to flow from a high to a low level for the same reason. In fact, it is often said that potential is to electricity what level is to water; and as in measuring elevations the sea level is taken as zero, so in measuring differences of potential, or differences in electrical level, the surface of the earth, which is nevertheless always slightly electrified, is arbitrarily taken as zero. Another analogy between level and potential may be permitted. Falling water does work in passing from a higher to a lower level; electricity in passing from a higher to a lower potential does work also, and in charging a body the same kind of operation is performed as in pumping up water. Work is expended in order that the capability for work may be produced.

The potential of a conductor may be varied in one of three ways: (1) by altering its charge (increasing the charge increases, diminishing the charge diminishes, the potential); (2) by altering its shape without altering its charge (because change of shape occasions a change of distribution of electricity); (3) by altering its position (because the electrical condition of a conductor is always affected by that of other bodies in its neighborhood, on account of the mutual inductive action which takes place between them). The potential of any given body, therefore, depends on its shape, size and position with reference to other bodies.

It is now possible to explain what is the cause of the initial charge in an accumulating influence machine. It arises from the very slight

potential difference existing between parts of the machine called the *inductors*, which fulfill the same office as the ebonite in the case of the electrophorus. This potential difference is increased by the action and re-action between the *carriers* (which correspond to the removable metal plates of the electrophorus) and the inductors. The carriers have charges induced in them by the potential difference existing between the inductors. They are then made to give up these charges to the inductors by contact, with the result that the potential difference between the latter is increased, and their consequent inductive action on the carriers made stronger, so that they are able to receive and convey more powerful charges. Since this process can be indefinitely repeated, a very small potential difference rapidly becomes a very large one, and the machine consequently able to produce extremely powerful effects.

In electrical study and practice it is often of great importance to determine what the exact potential of a body compared with some other body (often the earth) is. In order to fulfill this purpose instruments called *electrometers* are used.

FIG. 5.—Gold Leaf Electroscope, showing divergence of leaves at the approach of a rubbed glass rod.

The most familiar is the "gold leaf electroscope."[1] It consists of two strips of gold leaf placed inside a glass jar, and suspended by a wire which passes through a glass tube fixed in the cork, stopping the mouth of the jar. This wire terminates in a knob or else supports a flat piece of metal. When the gold leaves are unelectrified they hang straight down, touching each other ; but the moment any charge is communicated to them they diverge, being similarly electrified (see Fig. 5). This instrument is so sensitive that the smallest charge im-

[1] An *electroscope* is intended really to detect the presence and indicate the kind of electricity, but the gold leaf electroscope, though it can do this, is primarily a measurer of potential differences, and therefore an electrometer.

parted to it is made apparent. The chips cut from a cedar pencil and allowed to fall on the metal plate, are seen to be electrified, for as they touch the plate the leaves diverge. A rubbed glass rod approached within two or three feet from the instrument produces a marked effect, the gold leaves being then charged by induction. In the old form of this instrument, however (as depicted in Fig. 5), difficulties arose from the fact that if the glass shade were made as insulating as possible the gold leaves would feel the influence of *any* outside neighboring body, and therefore there could be no certainty with what the one under test was being compared. On the other hand, if the insulation of the glass shade was less carefully attended to, then the damp or dust collected on its outside would bring the latter to about the same potential as that of the earth, with which therefore the body under test could be approximately compared ; but then the imperfect insulation rendered it probable that directly the body was connected to the knob of the electroscope, it would be wholly or partially discharged, and therefore no longer of importance to test. Both these objections to the gold leaf electroscope have been overcome in the modern form of the instrument, devised by Professors Ayrton and Perry, in which the interior of the glass shade is coated with strips of tin foil, leaving only enough bare space to allow the gold leaves to be visible, and thus screening them from the influence of outside bodies, while the wire supporting the gold leaves passes through the top of the instrument, without touching it, thus greatly facilitating insulation.

It is curious to think that while the most advanced scientists are still unable to pronounce with any certainty what electricity is, they, and indeed every practical electrician, can measure this mysterious agent with the same unfailing accuracy that a tradesman can weigh out a pound of tea. Given any known combination of circumstances, and they will foretell precisely the behavior of electricity under those circumstances. There is a regular system of electro-static units, which need not be entered into here. They are based like the practical electro-magnetic units, of which a list and explanation will be given in a subsequent portion of this work, on the centimetre, gramme, and second as the units of length, mass, and time respectively.

As yet no source of electricity has been mentioned save friction, but there are many others, among the most important of which are magnetism, chemical action, heat, and the contact of dissimilar substances. The two first of these will require special chapters devoted to them, and the subject of thermo-electricity also falls more properly under the head of current electricity.

With regard to the contact of dissimilar substances, Volta was the first to discover that two metals allowed to touch each other become feebly electrified in opposite ways, there being a much greater

difference of potential[1] between some than between others. Thus when zinc is placed in contact with lead, it becomes slightly positive relatively to the lead; in contact with copper it is much more decidedly positive, and in contact with platinum the difference of potential is very considerable indeed. Volta arranged a series of metals (to which a few have been added since his time) in which every metal becomes positive if placed in contact with one lower on the list. This list is given at the end of the chapter, as it may be found useful for reference.

Two dissimilar liquids in contact also show a difference of potential, as do a liquid and a metal, and a cold and a hot metal.

Other sources of electricity will be treated of as occasion requires, but it is worth while to notice how entirely we are so far justified in the conclusion that electricity is not made by the exciting cause, whatever that may be, but only obliged to manifest itself by being forced into an unnatural condition. One evidence of this lies in the fact that neither positive nor negative electricity can be produced alone; an equal amount of the opposite kind is invariably forthcoming also. Another proof of the same thing is the possibility of charge by induction, in which the electrified state can be produced by mere influence, without any alteration in the quantity of electricity present. These considerations compel us to the belief that, whatever electricity may be, it is universally present, though we are often unconscious of the fact. Nor is this in reality a strange circumstance. It is probable that if the air were always in a state of perfect calm we should never know that such a thing as air existed.[2] We are rendered conscious of it by disturbances in its equilibrium, which cause the various winds. The same observation seems to apply to electricity. Some cause disturbs its equilibrium, and we then have too much of it in one place and too little in another, and the effort to restore equilibrium makes us conscious that electricity exists; but when it is only present in its natural state, *i. e.*, in one of perfect equilibrium, we do not know it is there.

List of metals in which every one is electro-positive to that next in order—

+ Sodium	Copper
Magnesium	Silver
Zinc	Gold
Lead	Platinum
Tin	Carbon —
Iron	

[1] For convenience' sake a positively electrified body is usually said to be at high potential and a negatively electrified body at low potential; but this is not really accurate, for there can be a high negative potential as well as a high positive one.

[2] See "Modern Views of Electricity," by Dr. Oliver Lodge, F. R. S.

CHAPTER IV.

THE LEYDEN JAR.

Importance of Leyden jar—Description—Electrical forces act across dielectrics—Capacity of conductors increased by proximity of opposite charge—And by earth connection—Definition of condenser—Discovery of Leyden jar by Cuneus—Method of charging and discharging—Residual charge—Important part played by dielectric—Real seat of charge—Bursting of jars—Battery of jars—Oscillatory nature of Leyden jar discharge—Further analysis of discharge—Sparking distance—Cause of its increase—Analogy with recoil—Cause of damping out and slackening of vibrations—Experiments by Dr. Oliver Lodge—Discharge of jar through circuit—Wheatstone's experiment—Velocity of discharge—Mechanical effects—Lichtenburg's figures—Magnetic effects of discharge—Physiological effects—Chemical effects.

THIS name is familiar to all, not excepting those "born in pre-scientific days;" for even then there were occasional quasi-scientific lectures given at schools and at country towns, at which the Leyden jar, thanks to its "shock"-giving capabilities, often played a prominent part, though it is doubtful whether the audience, or even in many cases the "lecturer" himself, understood the principle of its action. To electrical students of the present day this simple and, as some might suppose, antiquated apparatus is full of interest, for it involves facts as important and as wide-reaching as any of the more famous practical appliances of modern days; and only so recently as March, 1889, Dr. Oliver Lodge, in a discourse delivered at the Royal Institution, exhibited by means of the Leyden jar an entirely novel series of experiments illustrating some of the latest discoveries in electrical science.

The ordinary Leyden jar is a common glass jar, coated inside and outside to about four-fifths of its height with tin foil, and provided with a lid of dry, well-varnished wood, through which passes a thick brass wire, terminating on the outside in a metal knob, and communicating inside with the tin-foil, lining the inner surface of the jar. There are therefore two conductors, the two tin-foil coatings in presence of each other, separated by an insulating substance, *i. e.*, the glass jar. In Chapter I. it has been stated what happens when two conductors, one of which is electrified, are in close neighborhood and divided by the air. An induced charge in the originally unelectrified conductor is the result. If, instead of air, a sheet of glass were placed between the conductors, the induction would occur just the same; for glass and all insulating substances allow the electric forces to act across them, for which reason the name *dielectrics* is given to them. Though, however, all insulators are dielectrics, all are not equally good in this respect, nor does the best insula [illegible] best

dielectric. Dry air is a more powerful insulator than glass, but it is not so good a dielectric, *i. e.*, the inductive force does not act so freely across it. This is fortunate, as if air were as good a dielectric as glass our thunderstorms would be more violent and frequent. Substances which serve well as dielectrics are said to possess a high *inductive capacity*.

It has already been stated that charges of opposite nature in presence of each other are bound. They cannot avail themselves of the road of escape to the earth, even if open, because of the attraction each feels for the other. It follows from this, and has been proved by experiment, that the capacity of a conductor is increased by having near it another conductor oppositely charged. The two charges act on each other so strongly, they are (if the expression may be permitted), so occupied with each other, that they produce hardly any effect on surrounding objects, and are barely influenced by them. A conductor thus situated appears to be at a very much lower potential than it would if it were removed from the neighborhood of the oppositely charged body. If it is desired to raise the potential of a conductor when in presence of one oppositely charged to the same degree as when not so, a very much larger quantity of electricity will be required, which is saying in other words that the capacity of the conductor has enormously increased.

There is another circumstance which increases capacity. This is if the charged conductor be in presence of one not only oppositely charged, but connected to earth; for, supposing the latter to have an induced negative charge, it will if connected to earth lose some of its positive electricity, the negative charge becoming in consequence much stronger, and attracting yet more positive electricity into the conductor whose charge is of this sign. Consequently, a conductor close to one oppositely charged, which has an earth connection, is capable of accumulating very large quantities of electricity, and an apparatus made on this principle and for this object is called an *accumulator* or more often a *condenser*. Having said thus much, we may return to the Leyden jar, which was the earliest known and is one of the best of all condensers.

Its name is derived from the place where it was first invented or, to speak more correctly, discovered, which happened by pure accident. In the year 1746 Cuneus, a scientist of Leyden, wished to electrify some water. With this object he placed the liquid in a wide-mouthed glass vessel, which he held in his hand, allowing a metal chain from the conductor of an electrical machine to dip into the water. After some time, thinking the latter must be sufficiently electrified, he took hold of the chain to lift it out of the vessel, when, to his intense surprise, he experienced a severe shock, which so terrified him that he let fall the vessel, and wrote a few days afterward to Réaumur that he

would not expose himself to the same sensation again for the crown of France. What had really happened in the case of Cuneus and his glass vessel, was that he had unwittingly turned it into a condenser, the water serving as one conductor, his own hand as the other, and the glass, of course, as the dielectric. When, therefore, he connected the two conductors, by taking hold of the metal chain with his other hand, a discharge immediately took place through his body, occasioning the shock which so alarmed him, and which may be felt by any person who uses his hand to discharge a Leyden jar.

The ordinary method of charging is as follows: The jar is taken in the hand and its knob placed against the prime conductor of an electrical machine positively charged. Through the metal knob and wire positive electricity passes to the inner coating of the jar, and induces negative electricity on the outer coating, driving away the positive electricity of the latter to earth through the hand and body of the experimenter.[1] A stronger negative charge is the consequence, and its increased power of attraction draws more positive electricity into the inner coating, and the former process is repeated. The charging may be continued till the jar is electrified to the highest amount of which it is capable without bursting the glass, a contingency which always has to be guarded against. When charged, large sparks may be drawn from the jar by presenting the knuckle or one of the ends of a "discharging rod" to the knob—a discharging rod being simply a metal rod provided with glass handles, and jointed in the middle to allow of the two ends (which are knobbed) approaching each other. After the spark has been drawn the jar is found to be discharged, or, rather, apparently so; for if it be left some little time, and the discharging rod be then presented to it, a small spark may be drawn from it, showing that the jar could not have been entirely discharged by the first large spark. This second spark, which can never be obtained immediately, is due to what is called the "residual charge." Its return may be hastened by tapping the jar, which seems to show that its cause must lie in the molecules of glass not being able to return immediately to their natural condition after the strain put upon them, and its amount depends to some extent on the length of time the jar has been left charged, but also on the kind of glass of which it is made. In an air-condenser (a condenser formed by two conducting surfaces separated by air) there is no residual charge. This shows

FIG. 6.—Leyden jar with removable coatings. M M, metallic cases; G, glass jar.

[1] An insulated Leyden jar will not charge, because the potential of the rises equally, unless, of course, the coatings are connected, when they as one conductor with electricity of the same sign.

at once that a very important part is played by the dielectric; and a still more striking proof of the same thing is given by the fact that the real seat of the opposite charges in a Leyden jar is not the tin foil coatings, but the inner and outer surfaces of the jar itself, as has been proved by means of a jar with removable coatings (Fig. 6). If, after charging, the latter are taken away, they are found not to be electrified; on being replaced their charges at once return. This seems to explain the reason of a charge being always apparently on the surface of a conductor; in reality its seat is on that surface of the dielectric which touches the conducting surface, and not on the latter. It is the effort of the electricity to enter the dielectric medium which causes the "charge," viz., an accumulation of electricity unable to disperse itself. The Leyden jar is in truth a type of all "charge" and "discharge" phenomena, and in particular its conditions, as we shall hereafter see, are precisely those obtaining between two thunder-clouds, or between a thundercloud and the earth. It is this typical character which invests it with so great an interest. A third fact concerning it, which has already been mentioned, that if too highly charged it bursts, *i. e.*, a hole is pierced in the glass dividing the inner and outer coatings, points to the true explanation of what happens to a dielectric placed between two charged conductors. It is thrown into a state of strain, which if too great causes it to break. In the case of air such a rent is self-mending; with glass, of course, it remains, and a Leyden jar thus pierced is rendered useless. An instructive and significant fact is that a vacuum acts as a dielectric, clearly showing that the strain can exist without the presence of ordinary matter. The conclusion is therefore justified that it must primarily take place in the ether,[1] and be by it communicated to air, glass and other dielectrics.

If a Leyden jar be made sufficiently large, it is evident that it might accumulate an enormous quantity of electricity; but as very large jars are found inconvenient in practice, it is more usual to connect them together in such a way that they can, if desired, be all discharged at the same moment. Such an arrangement is called a "battery" of jars, and, if the latter be of high capacity, is a very powerful source of electricity.

The spark from a Leyden jar is of infinitesimal duration, lasting only a small fraction of a second, and it was formerly supposed to be due to a single discharge. Such is, however, by no means always the case. When the spark is examined by means of a very rapidly rotat-

[1] The name given to an imponderable, tenuous, and highly elastic medium which pervades all space and interpenetrates all matter, and through which heat, light, and electrical energy are propagated by means of radiation. According to the latest scientific theories, all electrical phenomena are caused primarily by strains and stresses in the ether. Further reference will be made to this subject in the concluding chapter of the present work.

ing mirror, it is often seen to be serrated, proving that the discharge which causes it is not a solitary rush, but a number of surgings backward and forward, that the discharge is in fact *oscillatory;* and the rapidity of these oscillations is such, that some hundreds of thousands take place during the minute fraction of time which limits the duration of the spark. This fact throws light upon one which would otherwise be inexplicable, viz., that a Leyden jar is most inclined to burst, not, as would be naturally supposed, before, but at the moment of discharge—no doubt because the glass, though able to bear the continued strain in one direction (which is the condition of things in a "charge"), gives way when that direction is reversed and re-reversed with such inconceivable rapidity, its force of recovery (or elasticity) not being equal to the demand made upon it.

The fact of the discharge of a Leyden jar being oscillatory does not at first sight appear to be of any great importance, but when we recollect that all charge and discharge are like those of a Leyden jar we begin to understand that such a discovery as this is of the highest moment, and must be intimately connected with any true theory of the nature of electricity.

It is not necessary for the discharge of a Leyden jar to take place by means only of the discharging rod; there are many other ways in which it can be effected, some of them very interesting and instructive; but there is one way in which neither it nor any condenser arranged in the ordinary way with one coating connected to the earth will discharge, and that is by means of a continuous flow of electricity to the earth or to another conducting body.[1] If a wire is fastened to a single charged conductor, and then connected to earth or to another conductor, a flow of electricity begins and continues till the two bodies are at the same potential; just as water contained in two vessels connected together, one of which is fuller than the other, will flow from the fuller to the more empty vessel till the water in both is at the same level. But, as we know, a Leyden jar is not a single charged conductor; it consists of two conducting surfaces separated by a dielectric, and it has two charges, not one charge, which, being thus in presence of each other, are bound and will not flow away to the earth. When the discharge takes place, therefore, it is on account of the strain to which the dielectric separating the two electricities is subjected, breaking it down; so that either a hole is pierced in the glass, or a rent made in the air between the knob of the jar and the discharging rod. It is in this kind of discharge that a spark passes, and the distance it can overleap is called the *sparking distance.* This increases with the difference of potential. A much

[1] It is to be observed, however, that if a discharging rod were applied with great suddenness to a charged condenser of considerable size, much of the discharge would then take place in the form of a flow between the two coatings.

larger spark can be drawn from a Leyden jar when highly charged, so that the coatings relatively to each other are very positive and very negative, than when feebly charged. It is, in fact, difference of potential which produces the spark at all, and consequently the greater that difference is the greater the sparking power will be. The well-known mechanical phenomenon of recoil helps to explain this. The rebound of a spring which has been stretched to its utmost extent is very much greater than when it has been only slightly stretched; and this analogy may help us also to a clearer idea of the oscillatory nature of discharge. The spring, when let go, flies beyond its natural position and then back again, overshooting the mark on the other side, so that before it settles down a series of oscillations takes place. A plucked violin string gives an example of the same thing; and it is what frequently happens in the case of the Leyden jar. Its discharge is then a series of partial discharges, caused by the electricity overshooting the mark and swinging back again, just as the spring or the violin string overshoots the mark and swings back again. The inner coating of the jar at the instant the discharge begins is positive; it then becomes momentarily negative, to return again to positive, and then back to negative, the charge becoming feebler with each vibration till it is entirely dissipated, just as the oscillations of the spring become smaller and smaller in range till they cease altogether and it is at rest. Clearly the greater the resistance the spring has to encounter in making these movements, the fewer they will be and the sooner they will cease; and we may illustrate the same fact by a pendulum. In air it will oscillate for a considerable time. In treacle it will not oscillate at all, but simply return to its position of equilibrium with a slow, sliding motion. The same thing is true of a Leyden jar discharge. The electricity may encounter very little resistance on its road, or it may encounter a good deal. In the former case the oscillations will be many and rapid; in the latter, few and slow; and it is even possible, as in the case of the pendulum in treacle, to put a stop to them altogether. The same effect as that of resistance may be produced by weighting a spring. A heavy violin string vibrates much more slowly than a light one; and something analogous to the adding of weight, but which cannot here be explained, may be done in the case of electricity.[1] Acting on this principle, Dr. Oliver Lodge was able to show some very remarkable experiments at the Royal Institution in March, 1889. He brought down the number of vibrations in a Leyden jar discharge from their usual frequency of about 1,000,000 a second to 500 a second, with the result that the sudden sharp crack of the spark was changed into a distinct musical note, and the line of light was seen

[1] It is accomplished by increasing what some electricians call the "self-induction," and others the "electro-magnetic inertia" of the circuit. See p. 78.

by the audience to be quite coarsely serrated by means of a mirror revolving only four times a second.[1]

It has already been said that a Leyden jar can be discharged in various ways; for instance, instead of a discharging rod being used, and one end made to touch the outer coating, while the other is approached close to the knob connected with the inner coating, wires may be fastened to each of the coatings and made to pass round a considerable space, or coiled many times on themselves, before their respective free ends are brought near together. When this is done, however, a spark passes between the two, just as it does between the discharging rod and the knob of the jar. Such an arrangement is called a *circuit*, and several intervals may be left in it, all of which the spark will overleap, provided their united length does not exceed that which it could pass at one jump.

Apparently the discharge takes place as instantaneously when the electricity has to travel through many yards of wire before arriving at "sparking distance" as when the discharging rod is used. This is not really the case, however; and by a celebrated experiment (which, broadly described, consisted in connecting each of the coatings of a Leyden jar with a considerable length of wire, and arranging three small intervals side by side across which sparks had to pass)[2] Sir Charles Wheatstone determined the velocity of transmission through copper wire to be at the rate of 463,133 kilometres or 288,000 miles a second. Other experimenters have, however, obtained different and very much slower rates, and in any case it must not be supposed that this experiment really proved anything at all about the "velocity of electricity." It simply showed that through a conductor of given resistance and capacity a certain electric effect took a definite though infinitesimal time to travel, which would not be the same through a conductor differing in either or both of these respects.

The heating and luminous effects of discharge have been already mentioned. Its mechanical effects are of equal importance and interest. The electric whirl is one of these. Another is the perforating of paper or cardboard by passing the electric spark through them; and a remarkable fact is that the edges of the paper round the hole

[1] For a detailed report of the above experiments and the discourse which they illustrated, see *The Electrician* for March 15, 1889.

[2] The test was as follows: The central interval was that which the spark had to pass *after* the two electricities had made the journey through their respective wires; the side intervals they encountered almost immediately. If the transmission had been instantaneous, the sparks examined in the rotating mirror would have presented three parallel lines. Instead of this their appearance was thus when the mirror turned from right to left, and thus when it turned from left to right, showing that the central spark began after its companions, and also proving the double flow, since one side interval was in the wire coming from the negative, and the other in that from the positive coating.

will be found turned up on *both sides* instead of only on one, as in an ordinary perforation by burning. Formerly this was supposed to be a proof of the double current; it is now, however, rather considered to be a consequence of the mechanical effects of the current spreading equally in all directions. Lichtenburg's dust figures also show the mechanical power of electricity. They are made by means of two powders (often vermilion and sulphur) being shaken together in a muslin bag and then sifted on to a cake of resin. The friction causes the powder particles to become electrified, the vermilion positively and the sulphur negatively, consequently the negative parts of the resin attract the vermilion and the positive the sulphur, so that the two powders arrange themselves in distinct and quite different shapes.[1]

Of other effects of discharge, that on the magnetic needle must be mentioned. It is deflected from its true position when close to the place of discharge; and during violent thunderstorms ships' compasses have often been rendered quite useless, owing to the influence of the lightning on them. A steel needle may be made into a permanent magnet by being placed within a wire spiral through which a discharge is passed. Discharge also produces considerable physiological disturbances, which are most strikingly illustrated by lightning, and will therefore again be referred to under the head of atmospheric electricity; but powerful electrical machines and Leyden jar batteries can produce effects quite as marked, and sometimes fatal where proper precaution is neglected. Even a single ordinary jar may give a very unpleasant shock, as Cuneus and many others have proved. The "return shock" experienced by persons standing at a little distance from an electrical machine which is being discharged, or from some object "struck" by lightning, is due to induction. The effect of the charged conductor (whether a cloud or the prime conductor of a machine) is to induce a charge of opposite kind in all neighboring objects. When it discharges, they follow its example, their charges being no longer bound, and the consequence to a living body is a "shock."

Lastly, a discharge passed through chemical compounds causes their decomposition, and its effect on the air, as we have already seen, is the production of ozone.

[1] Another way of making these figures is by tracing a pattern on the resin with the knob of a charged Leyden jar and then sifting the powder over it.

CHAPTER V.

ATMOSPHERIC ELECTRICITY.

Identity of lightning and electricity—Franklin's kite experiment—Its repetition by Romas—Danger of these experiments—Death of Richman—Existence of atmospheric electricity independently of thunderstorms—Results of modern observations—Daily variations—Annual variations—Electrified clouds—Signs of atmospheric electricity in dry, cold weather—Ozone—Its importance to health—Not found in contaminated air—Same true of positive electricity—Ozone an active chemical agent—The Aurora Borealis—Frequent appearance in high latitudes—Description—Resemblance to discharge through rarified gases—Probable origin—Effect on the magnetic needle—Improbability of its being attended by sound.

MANY early observers noticed the resemblance between the flash and crack of the electric spark and those tremendous natural manifestations, lightning and thunder. It was reserved for the great American philosopher, Benjamin Franklin, however, to establish their identity by actual experiment. Having observed that lightning usually strikes the most elevated objects, he resolved to erect a sort of sentry-box on some high tower, from which a pointed and insulated rod could be raised, and thus enable him to make his observations. Before this could be accomplished, his fertile brain suggested another expedient to which resort could be had the first time a thundercloud approached, and which therefore he determined to adopt. This was to use a common kite, suitably prepared. He made one of silk, fastened an iron point to it, and furnished it with a string, the upper part of which was of ordinary twine, but the lower part of silk. At the junction of the two he attached a key. At the first sign of a thunderstorm he went out into the country, accompanied by his son, and let fly the kite. At first, to Franklin's intense disappointment, no signs of electricity were obtained, but in a short time he noticed the loose fibres of the string begin to bristle, and holding his knuckle to the key, a bright spark passed between the two. Rain then fell, the string became wet, and its conducting powers consequently much better ; and in a short time numerous large sparks were drawn from the key, proving beyond a doubt that Franklin's surmises were correct, and lightning and the electric spark identical. This celebrated experiment was made at Philadelphia in 1752.

In 1753 it was repeated on a very grand scale by the Frenchman Romas, and in presence of several spectators, Romas himself receiving a very severe shock, which warned him to use a discharging rod instead of his knuckles to draw the sparks, the latter being so powerful that they appeared like flashes of fire a foot long, and were accompanied by a noise audible at 500 feet distance. At the commencement of this experiment no rain was falling ; when it began to do so a grea

increase of electricity was perceptible, and Romas dared not draw sparks even by means of the discharging rod. Both he and the bystanders experienced the peculiar sensation, "as though a spider's web had been upon the face," which is sometimes felt near an electrical machine, and the explosions and flashes of fire were attended by the strong and characteristic smell accompanying a violent lightning discharge and the working of electrical machines. This odor was described by nearly all early observers as "sulphurous," but in reality it more resembles that of phosphorus, and is now known to be due to the production of ozone.

It is evident that experiments of this description, unless conducted with the very greatest care, are in the highest degree dangerous, and before long a fatal accident checked the growing ardor of the scientific world for making them. On the 16th of August, 1753, Professor Richman, of St. Petersburg, while conducting experiments during a thunderstorm on an insulated iron rod, projecting from the roof of his house and carried down into the room where he worked, was killed by a sudden flash of electric fire which darted from the rod with a loud report. So terrible a warning was not unheeded, and experiments on lightning became very rare; in fact, it may be said that since this period hardly any have been undertaken, though many facts and observations have been collected, and the rapid growth of electrical science has enabled practical men to grapple, to a very great extent successfully, with the problem of protection from injuries to life and property due to lightning.

Before entering upon the subject of thunderstorms, which are occasioned by an abnormal electrical condition of the atmosphere, it will be well to glance at what that condition is when no storms are in progress.

The discovery that electricity exists in the atmosphere quite independently of thunderstorms was an almost immediate consequence of Franklin's famous experiment with the kite. The Abbé Mazeas discovered in 1753 that signs of atmospheric electricity could be obtained in fine dry weather at all hours between sunrise and sunset; and Franklin himself attached a pointed iron rod to his house, which could be insulated when he chose, and to which he connected a system of the electric chimes previously described. Whenever the conductor was affected by the neighborhood of some charged cloud, the chimes began to ring, and Franklin's attention was drawn to the fact that a favorable time for his observations had arrived. His apparatus did not enable him to ascertain more than that ordinary clouds were sometimes positive and sometimes negative, more often the latter; and no very great advance was made in the knowledge of atmospheric electricity till the electroscopes and electrometers of modern days were applied to this purpose. And even now but little has been positively

ascertained on this subject. From observations made at various times in different places, and compared and verified by eminent men of science, the following facts have, however, been elicited. The potential of the air increases with increase of distance from the surface of the earth, which might be caused by the latter possessing a negative charge, but it is not known whether this is really the case. In fine, calm weather, the atmosphere is positive;[1] in cloudy, rainy and windy weather it is very often negative, but will sometimes change rapidly from one sign to the other. Clouds are always electrified, and often to a very high potential. Usually they are positive, but there are many exceptions. The electrical condition of the air is subject to daily and annual variations. Every twenty-four hours there is a decrease of electricity, beginning an hour or two after midnight and continuing till shortly before sunrise, when an increase commences and goes on until some hours after sunrise, when the first maximum is attained. The electrical condition of the air then remains stationary for a short time, after which another decrease sets in until some hours after noon, when a minimum is reached. Another short pause ensues, and then a second increase takes place, attaining its maximum some hours after sunset. Then occurs the second decrease, reaching its minimum about midnight. Many local causes, however, may modify the ordinary electrical condition of the air and its daily variations. Fogs are highly electric, and their presence always considerably raises the potential of the atmosphere. Snow-storms accompanied by high wind are sure to produce very strong indications of electricity, and this fact favors the idea that one important source of atmospheric electricity may be the friction against each other and the earth of solid and liquid particles, brought about by the wind.

The annual variations of atmospheric electricity consist in a gradual increase beginning from May or June and attaining a maximum in one of the winter months, varying with the locality in which the observations are made, and a gradual decrease commencing from the time of maximum and continuing until a minimum is reached in the early summer. It is, therefore, during the winter months that the air is most highly electrified, a circumstance which may perhaps surprise those who are accustomed to think of thunderstorms as the only signs of atmospheric electricity, for these in our climate are far more common in summer than in winter. It is not, however, a uniformly high potential which occasions storms, but great differences of potential, and these occur in England more frequently in summer than in winter, owing to the larger amount of evaporation which is going on.

[1] The lower strata of the atmosphere are non-conducting when dry. It is at some distance above the surface of the earth that indications of positive electricity are obtained. According to some recent observations, earthquakes appear to occasion a negative electrification of the air.

Vapor in considerable quantities rises from the earth and sea, drawn up by the heat of the sun, and on reaching the higher and cooler layers of air, condenses. Now, evaporation has been proved by experiment to be always attended by a development of electricity; and the vapor particles are therefore all in an electrified condition. When they condense into a drop, their united electricity spreads itself (according to the laws of electrical equilibrium) over the surface of the drop, which, however small it may be, is far more highly electrified than any one of the vapor particles which have gone to form it. These minute drops again coalesce into larger ones, with the result of a still further raising of potential, and a cloud which is formed of an incalculable number of such electrified drops attains a very high potential indeed, and becomes capable of exerting a strong inductive influence on neighboring clouds and on the earth, and thus of giving rise to thunderstorms. Though atmospheric electricity is not indicated in this way during winter, or at any rate but rarely, it gives other less obtrusive signs of its presence. It is in the winter months that single well-isolated objects become most easily electrified; every one knows that the peculiar crackling of the hair when combed occurs almost invariably in dry frosty weather, and articles of clothing will also then frequently show signs of electrification. Rubbing the hand briskly against flannel or any woolen material, occasions a crackling noise accompanied, in the dark, by sparks; and brushing woolen garments will often cause them to become more dusty than before, owing to the friction electrifying them and making them attract small floating particles of matter. In New York, where very dry and intense cold is experienced in winter, these electrical effects are very marked; the dryness of the air in dwelling houses being increased by the method of warming, and the insulation of different objects by the thick woolen carpets used. It is stated that "if one move upon such a carpet with a sliding or scraping motion, and then present the knuckle to a metallic conductor, such as the handle of the door, an electric spark accompanied by a crackling noise will be perceived. If one goes in this way once or twice quickly along the carpet, the spark may be three-quarters of an inch long, very brilliant and accompanied by a tolerably loud noise."[1] In order to observe these phenomena well, the carpet should be entirely of wool and thick. The authority above quoted gives an amusing account of a visit to a lady in New York in a house where the conditions were particularly favorable. She drew brilliant sparks from the gas chandelier; a visitor advancing to shake hands with her, would receive a perceptible shock, and a spark would pass between herself and a lady friend bending to salute her.

The dry cold weather which is best adapted to the manifestation

[1] "The Thunderstorm," p. 289.

of these and kindred phenomena is considered particularly favorable to health, most persons then experiencing a feeling of much greater physical briskness and activity ; and it does not seem improbable that this may be partly owing to the more highly electrified state of the air. In any case, electricity must certainly be considered an important salubrious agent, for to it we apparently owe the existence of ozone, on the necessity of which modern sanitarians insist so strongly. As has already been stated, ozone is a modified and much more active form of oxygen. Its presence in large quantities (as during the working of an electrical machine) is made known by a strong and peculiar odor, but in thoroughly good and pure air there is always a small amount of ozone, and its absence is a sign that the atmosphere is in some way contaminated. It is not found in crowded rooms, in the confined courts of large cities, or in any place infected by the breath of men or animals. In the open squares of towns, on bridges and quays, and, in fact, wherever the air is easily renovated, and consequently pure, indications of ozone are readily obtained ; and it is worth while to observe that the same remarks apply to positive electricity, no traces of which are discoverable in close and confined quarters, or in crowded streets and dwellings. Beside its health-giving properties, ozone is an active chemical agent ; it is a very rapid oxidizer, and possesses strong bleaching powers ; and organic substances exposed to its influence are corroded.

The last and most remarkable electrical phenomenon which will be mentioned in this chapter is the Aurora Borealis. All travelers in the far north are well acquainted with its changeful and exquisite light, so vivid as to clothe with glory the winter darkness of the Arctic regions ; but even in England the Aurora is often visible, though far less brilliant than in higher latitudes. On one occasion, in early winter, the writer witnessed an exceptional display of its beauty. The whole northern horizon was covered with a deep rosy glow from which pale streamers extended far up into the heavens. Even this, however, was but a faint representation of the "Northern lights" as they are known to the inhabitants of the Polar regions, where they are described as often equal to the full moon in brilliancy, appearing in the most exquisite arches, continually melting one into the other to reappear in new and more beautiful forms, and varying in color from a silvery whiteness to deep shades of orange and rose color. The motion of the auroral streamers which start from the arches or glow is often exceedingly quick, and has gained for them among the inhabitants of the Shetland Isles the name of "The Merry Dancers." They change rapidly in form, die away in one place to break out in another, and are generally animated by a strong tremulous motion from end to end. This tremulous motion is like the flickering of the light caused by passing an electric spark through an exh

and, in fact, the two phenomena resemble each other almost as closely as do the electric spark and a flash of lightning. It is therefore natural to refer their existence to a similar origin, and the Aurora Borealis is considered to be due to electric discharges taking place in high and therefore very rarefied strata of the atmosphere. The actual proof that its origin is electric lies, however, in the fact that the presence of the Aurora invariably affects the magnetic needle, making it deviate from its true position, and that often to a considerable extent, and over very large areas of the globe. The Aurora does not always appear in the due North, but frequently toward the East or West, and sometimes at both points simultaneously; neither is it always arched, but appears occasionally in strips, or in "undefined luminous clouds." Its position in the heavens is thought to affect the weather; thus after an Eastern Aurora, dry cold is expected, whereas one in the West is supposed to cause storms and snow, and Auroræ in both quarters simultaneously, unsettled weather.[1]

Early travelers frequently said that a peculiar "hissing, crackling, and rushing noise" accompanied very brilliant displays of the Aurora, but no such sound has ever been heard by any scientifically trained observer, or, indeed, by any observer at all in modern times: and the fact of the Aurora taking place in very rarefied air, renders its being accompanied by sound highly improbable. The appearance of these heavenly fires, which is frequently such as to give the impression of their being carried along by an impetuous wind, irresistibly suggests the idea of a "rushing" sound as their fit accompaniment, and this may easily have given rise to the belief that it had been actually heard.[2]

The Aurora is seen in the South Polar regions as well as in the North, and is then called the "Aurora Australis;" but these Southern lights, though still very beautiful, are not so striking and brilliant as the Northern.

[1] "The Thunderstorm," p. 299.

[2] M. Gaston Planté nevertheless credits the reality of this sound, and attributes it, as he does that which accompanies globular lightning, to the sudden vaporization of liquid particles by the passage of the electric discharge ("Phénomènes électriques de l'Atmosphére," p. 146).

CHAPTER VI.

ATMOSPHERIC ELECTRICITY CONTINUED—THUNDERSTORMS.

Analogy between Leyden jar and conditions giving rise to thunderstorms—Reason of repeated discharge in the latter—Short duration of lightning—Brilliancy—Color of lightning flashes—Shape—Forked lightning—Cause of ramification—Possibility of the light of one flash producing another—Bifurcation—Sheet lightning—Thunder—Globular lightning—Planté's experiments—His conclusions from them—Chemical effects of lightning—Heating effects—Fulgurites—Explosive effects—Probable cause—Examples—Length of lightning flashes—Altitude of thunder-clouds—Magnetic effects of lightning.

IT was stated in Chapter IV. that the conditions giving rise to thunderstorms are the same as those of a charged Leyden jar. We may go a little further than this, however, and say that possibly the inhabitants of the earth live in a huge Leyden jar, which is usually but slightly charged, but may at almost any moment become electrified to a very high degree. The earth's surface, which there is reason to believe may be always faintly negative, would form one coating of this jar, the clouds and upper strata of the atmosphere the other, and the air between would be the dielectric. Now, if owing to rapid evaporation and condensation, or to other of the various causes which generate and increase atmospheric electricity, clouds form whose potential is very high, they act inductively on the surface of the earth and all objects which rise from it, and these become strongly charged in the opposite way, the air between the clouds and the earth being thrown into a state of strain exactly similar to that of the glass in a Leyden jar. By and by this strain becomes so great that the air gives way under it, a rent is made, a dazzling flash of lightning is seen, a loud roll of thunder heard, and a beginning of discharge is made; but a beginning only, for, as we well know by experience thunder-clouds do not discharge themselves at once like Leyden jars; the lightning and thunder will often continue for hours with but little interval between the flashes, and no diminution in their brilliancy. The reason of this lies in the way in which clouds are formed of innumerable drops, each one electrified and each one insulated from its neighbor. Because of this a cloud is electrified throughout its whole mass, and not only on its surface; therefore, so soon as one surface discharge is over, more electricity replaces that which has been dispersed, and a similar state of strain recurs, to be relieved by another discharge, rarely, however, following exactly the same path as its predecessor. Discharges take place between different clouds, as well as between clouds and the earth. In the former case there may be no danger to be apprehended, but in the latter very serious and alarming consequences often ensue; though the use of lightning

rods, imperfect as the latter may still be in some respects, has certainly diminished the number of accidents to life and property.

The two principal characteristics of lightning are its short duration and its extreme brilliancy. A flash of lightning is thought to last about one ten-thousandth part of a second. This fraction of time is so minute that it is difficult to form an idea of it, but a rough notion of the momentariness of lightning can be obtained by observing that an object moving at however great a speed, the wheels of a carriage, or of a train, appear absolutely stationary when seen by it. Even a rifle ball would look as if poised motionless in mid-air. One experiment which has been made proving this extremely short duration of lightning, is to observe during a flash a very rapidly rotating disc, painted in alternate black and white sectors, running from the centre to the edge like the spokes of a wheel. By daylight such a disc appears gray while revolving, as its speed is so great as to allow no time for the eye to distinguish between the black and white, which are consequently mixed together and form gray. Seen by a lightning flash, however, the black and white sectors stand out clearly with gray ones between them, the fraction of space through which one sector is able to move while the flash lasts being so small as to produce almost the same effect as though it were stationary. In order to produce exactly the same effect and have no gray at all, it would be necessary for the illumination to be really instantaneous, which is impossible.

One consequence of the short duration of lightning is an apparent diminution of its brilliancy. It has been proved that light cannot produce its full effect on the eye unless it remains, at least, as long as one-tenth of a second. But lightning lasts only the ten-thousandth part of a second, and it follows from this that we see it one hundred thousand times less bright than it really is. When we recollect that even thus diminished its brilliancy is such as to cause temporary blindness if too closely watched, we may feel grateful that we cannot see it in its true vividness, for any human powers of vision would be too weak to bear such a sudden and overwhelming illumination.[1]

The color of lightning varies according to the condition of the atmosphere. If the latter be saturated with moisture, red will probably be the predominating hue, because the intense heat developed by the passage of the flash decomposes and rarefies the air and the watery vapor it contains. If, therefore, the latter be abundant, rarefied hydrogen, which is red when an electric discharge passes through it, will give its hue to the lightning. If, on the contrary, the air be

[1] It should be stated, however, that there is some evidence, chiefly photographic, that lightning flashes may at any rate occasionally be of longer duration than is usually supposed, and the magnetizing power of lightning also points to this conclusion. See the discussion on lightning-rods during the meeting of the British Association at Bath, 1888.—*Report of the British Association* for 1888, pp 593, 598, 601.

comparatively dry, or the quantity of electricity in play not very large, the color of the flashes will be blue or bluish-violet, which is that of rarefied air during the passage of an electric discharge.[2]

The shape of a flash of forked lightning varies according to its length, and the equality of resistance it encounters in its path from a cloud to the earth, or from one cloud to another. If the distance be short, and the air of a tolerably uniform density, the flash may be nearly or quite straight; but if there is a long way to traverse, and the air is in different states of density at different points (as is almost invariably the case during a thunderstorm), the flash is sure to pursue a very irregular and winding path, sometimes seeming to meander

FIG. 7.—From a photograph taken in the early morning of June 7, 1889, at Peterborough, by Mr. A. W. Nicholls.

about in the air, sometimes even making loops and knots in its progress (Fig. 9), and in all cases frequently giving out side flashes, as represented in Figs. 7 and 8.

The cause of the irregular path of a lightning flash lies in the tendency of electricity to take the path of least resistance; it would rather run round an obstacle, if possible, than overleap it, and a long electric spark will often exhibit on a small scale exactly the same peculiarities of shape as a flash of lightning, and for the same reason.

[2] Planté, "Phénomènes électriques de l'Atmosphére," pp. 34, 35.

The forking or, to speak more correctly, the branching of the lightning (for, seen in a photograph, one flash often seems to ramify into others, like the roots or branches of a tree, Fig. 7) has a different

FIG. 8.—From a photograph taken by Mr. C. A. E. Pollock, at Corpus College, Cambridge, on the night of June 6, 1889.

cause. It is thought that one lightning flash gives rise to others following nearly, though not quite, the same direction as itself; and

FIG. 9.—From a photograph by Mr. A. K. Baird, taken at Edinburgh, on June 6, 1889, about 9 P. M.

when we remember that the cause of lightning is the break-down of the air under the strain to which it is subjected, this hypothesis becomes exceeding probable, for all round the path of the flash, and

not only in it, this same strained condition obtains, so that the mere shock of the air giving way at one point would seem to render its giving way at the other neighboring points almost a matter of certainty.

There is another way in which one lightning flash may, perhaps, be the cause of others—a way which is particularly interesting because it serves to show the exceedingly intimate connection between light and electricity. It is a curious and remarkable fact that if the light of an electric spark is made to fall on the space between two conductors, which are highly charged but just not able to spark into each other, they will at once do so, especially if the light fall on the conductors themselves—showing that under certain conditions the mere effect of light is able to produce an electric discharge. Now, since lightning is in reality simply a very enormous electric spark, it is only reasonable to suppose that it will behave like one, and, therefore, that

FIG. 10.—From a photograph taken in the early morning of June 7, 1889, at Peterborough, by Mr. A. W. Nicholls.

under some circumstances the *light* of one flash will cause another flash. The probable reason of this phenomenon can only be briefly alluded to, but it is of too great interest to be passed over entirely. It has already been stated both that the discharge of a Leyden jar is often oscillatory and that it is the type of all discharge, including that of lightning. It follows, then, that lightning discharge may be oscillatory. Now, in a medium able to transmit them, oscillations or wave-movements spread; and with light and electricity the ether is the medium through which they spread, as air is the medium through which sound waves spread. In the case of sound, it is well known that if two tuning-forks of the same pitch be placed near each other, on striking one the other will give out its note also; this is because the vibration of the first, communicated through the air to the second, sets up in that a similar vibration. It would seem that an electric

spark, or a flash of lightning caused by the light of another spark or flash, must have an analogous origin. A vibration is set up by the first flash, which is communicated through the ether to the point where the state of things is such that another similar vibration can be set up, and a second flash is the result. Such a combination of conditions may be rare (it is not always that we find two tuning forks near at hand able to be excited the one by the other), but it is certainly possible, and its occurrence, if it could be proved, of the very highest interest.[1]

A single flash of lightning will sometimes divide when it strikes an object, and take two or even more different paths for the rest of its journey to the earth, working destruction in each, unless very efficient lightning conductors be provided. Some description of these and the injurious effects they are intended to guard against, will be given shortly. In the meanwhile mention must be made of the second kind of lightning flash, the *sheet*, and of a third, which is not a flash at all and is but seldom seen, viz., *globular lightning*.

Sheet lightning presents the appearance of a broad flash, emanating from the edge of the cloud, or occasionally from the centre, when the cloud looks as if it opened to allow of the exit of the electric fire. No object on the surface of the earth is ever struck by it; it is, in fact, a discharge between cloud and cloud, much of the nature of a brush discharge, and not a discharge between a cloud and the earth. Occasionally sheet lightning is seen on a clear sky and unattended by thunder, and it is then often called summer or heat lightning. This is no doubt reflection of flashes from a storm below the horizon, and too distant to allow the sound of the thunder to reach the ear of the observer. The thunder itself is supposed to be due to the sudden and violent expansion of the air caused by the enormous heat developed in the path of the lightning. The rolling sound is occasioned partly by echoes from the different surfaces of the clouds and from strata of air of unequal density, and partly by the great length which a lightning flash sometimes attains. The flash is practically simultaneous along its whole path, but since sound takes a very much longer time to travel than light, moving at the rate of only about 1,100 feet

[1] Professor Rowland appears to think that the "return shock" (which in the case of a lightning flash often takes place at a very considerable distance from the actual point of discharge), may be explained on a similar principle. In a lecture given at New York, before the American Institute of Electrical Engineers, he said: "If they (the oscillations) take place, we have a ready explanation of what is sometimes called a back-stroke of lightning. That is, a man at the other end of the cloud, a mile or more distant from the lightning stroke, sometimes receives a shock, or a new lightning flash may form at that point and kill him. This may be caused, according to our present theory, by the arrival of waves of electrical disturbance, which might themselves cause a slight shock, or even overturn the equilibrium then existing, and cause a new electric discharge."

a second, the noise of the thunder, though started at the same time throughout the entire line of discharge, reaches the ear by degrees, the sound from the nearest point first and that from the points farther away afterward, according to their distance.

Globular lightning, *i. e.*, lightning having the appearance of an intensely brilliant luminous or fiery ball, was long held to be fabulous, and the accounts of it have certainly often been greatly and even ridiculously exaggerated. Nevertheless, there remains now no manner of doubt that this phenomenon, though rare, compared to that of forked or sheet lightning, does most unquestionably occur.[1] Persons trained to scientific observation have recorded its appearance, and their accounts tally in the main particulars with those of other observers. Globular lightning may either descend from the clouds[2] or ascend from the earth,[3] or it may float along at a greater or less distance from the soil.[4] Its movement is slow and its path often extremely capricious. Its duration varies from a few seconds to a minute or more. Its disappearance is sometimes noiseless and harmless, sometimes attended by a loud explosion and disastrous effects. Some accounts have described these fiery balls entering the window of a house and going up the chimney. This is probable enough, as the column of hot air would make an excellent conducting path for the electric discharge. Owing to the same cause, no doubt, there have been accounts of similar visitors coming down the chimney, to the great consternation of the witnesses. Globular lightning has been observed in the centre of thick clouds during a thunder-storm, and passing between one cloud and another,[5] and also occasionally with a rotatory movement.[6]

Many of the phenomena of globular lightning have been artificially reproduced on a small scale by the late eminent French electrician, M. Gaston Planté, whose experiments were, however, conducted by the aid of current, not static electricity. He used powerful secondary

[1] The writer in the year 1870 herself witnessed an appearance of globular lightning. It occurred in Wiltshire during a heavy thunder-storm, which, not being immediately overhead, allowed of a continued observation of the lightning flashes. These presented nothing specially remarkable. The storm was in the neighborhood of the Westbury Downs, at some distance above which there was a thick, leaden canopy of cloud. Toward the end of the storm there fell from this cloud an egg-shaped luminous body which apparently dropped to some point on the hills, where it disappeared. Some seconds afterward there ensued a long, heavy roll of thunder. As the hills are distant about three miles, as the crow flies, from the place where the writer was situated, this luminous globe would appear to have been of considerable size. Its brilliancy was apparently that of ordinary forked lightning observed from the same distance, but its motion very much slower, the globe remaining visible for two or three seconds. No rain was falling at the time.

[2] "Phénomènes électriques de l'Atmosphère," p. 201 ff.

[3] *Ibid.*, p. 214 ff. Forked lightning also, though rarely, ascends.

[4] *Ibid.*, p. 47. [5] *Ibid.*, p. 207. [6] *Ibid.*, p. 202.

batteries,[1] which give currents of a very high potential, and succeeded by their means in producing small and intensely brilliant globules of fire on the surface of water, on a sheet of mica placed between two conducting surfaces, and lastly in the air-space between two damp sheets of filtering paper.[2] These luminous globules behaved in the same manner as globular lightning. They moved slowly, followed, in the second and third cases, very irregular paths, and their duration was considerable. M. Planté was led by his experiments to the conclusion that globular lightning must be produced by "dynamical" electricity (*i. e.*, current electricity) of very high potential and in large quantities, and that the fiery globes themselves are formed of "rarefied incandescent air and of the gases resulting from the decomposition of vapor of water also in a state of rarefaction and incandescence."[3] The brilliancy of these globes is due, according to M. Planté, to the quantity of electricity in play at the time of their appearance, and it is a fact that they are only observed during storms of exceptional severity. The rustling noise which often accompanies them he refers to the rapid vaporization of liquid and solid particles in the path of the electric discharge, and the variation of color to the same cause which produces it in ordinary lightning.[4]

Lightning produces chemical changes similar to, but on an enormously larger scale than those of an electric spark. It is often attended by a copious generation of ozone, to which fact may be referred the powerful odor often mentioned by persons who have been near an object "struck" by lightning. It also decomposes the oxygen and nitrogen of the air in order to form nitric acid, strong traces of which are found in specimens of rain-water collected during thunderstorms, while at other times it is either entirely absent, or present in almost infinitesimal quantities. The heating effects of lightning are also very great; it fuses and even vaporizes metals; but perhaps the most wonderful examples of its power in this way are the fulgurites or tubes of vitrified sand found in many places, and now known to owe their origin to lightning. Some remarkable tubes of this kind were found near Drigg, in Cumberland, in 1812, one of which was considerably more than thirty feet in length, and varying in diameter from an inch and a half, at the surface of the sand hill in which it was found, to half an inch at the bottom of the excavation made. Small branches, two or three inches long, and a quarter of an inch in diameter, protruded from the main stem. The outer surface of these tubes was rough and uneven, but the inner surface was formed of a "whitish or limpid vitrified matter, covered with a smooth glaze, and hard enough to scratch glass."[5] Similar tubes were found by Darwin in South

[1] See Part III. chap. i. p. 77.
[2] "Phénomènes électriques de l'Atmosphére," chap. i.
[3] *Ibid.*, pp. 29, 30. [4] See p. 40. [5] "The Thunderstorm," p. 117.

America, near the River Plata,[1] and attempts have been made with partial success to imitate them artificially, by means of passing a powerful electric discharge through various hard, powdered substances. The experiments succeeded with glass dust, a tube an inch long having been formed in this way, but failed with felspar and quartz, out of which lightning has nevertheless manufactured tubes thirty feet in length.

The most remarkable of all the effects due to lightning, however, are the extraordinary explosions it causes, and which have been attributed to the sudden vaporization of any moisture contained in the solid materials, such as stone, wood, etc., through which the discharge is passing. The formidable expansive power of steam is well known, and we may therefore conceive that if all the moisture contained in a tree or in a mass of stone were suddenly turned into vapor, the pressure would be such as to burst everything before it.[2] Instances of explosive effects in buildings will be given hereafter. With regard to trees, it is stated that "on the 25th of May, 1842, at the village of Adforton, near Ludlow, lightning struck a poplar tree nearly forty-five feet high; it was shivered to pieces, and the ground for a hundred yards round it was thickly covered with splinters, from four to twelve inches long, many of which seemed to be entirely smashed. The body of the tree was divided into eight or ten large portions, which came away with the branches and fell wide of each other, but all on the South side.[3] This is one example out of many equally remarkable.[4] Still more striking are some of the explosive accidents due to lightning on board ship. On 19th September, 1812, H. M. S. Sultan (of seventy-four guns) was struck by lightning off the coast of Sardinia; "the highest spar, or top-gallant, and royal mast was fairly shaken in pieces; the next, or top-mast, seventy feet long, was burst into shreds like a bundle of laths, and stood gaping open in the upper end; it remained in this condition for some minutes, and then fell with a terrific crash. So complete was the destruction that the decks of the ship were filled with the chips of wreck of more than three tons of wood. The next, or lower mast, weighing eighteen tons, was struck through to the very centre; and the lightning made

[1] "Journal during the Voyage of the Beagle," pp. 43, 44.

[2] Arago's theory as quoted in "The Thunderstorm," p. 122.

[3] "The Thunderstorm," p. 127.

[4] A very similar but not quite so destructive flash is mentioned in "The Electrician" for 27th June of the present year. During a storm at Playford in Suffolk, "a poplar tree, about 300 yards away from the church, was struck by lightning, and the bark was completely stripped away from top to bottom, the Southern half of the body being riven into matchwood. One piece, 5½ lbs. in weight, was picked up 120 yards away from the tree, and the débris covered about two acres of land. The discharge left the tree at the foot, following the direction of a fence for about 15 or 20 feet, threw up a sod about a foot square, and went to earth."

one or two holes in it sufficiently large for a boy to creep into. The chips which were torn out were thrown about the deck. It was with difficulty prevented from falling till the ship got into port, when the mast in its ruined state was taken out. On removing the moldings and fishes it literally fell to pieces."[1]

The length of lightning flashes has been very variously computed, some authorities considering that it may be a mile or even more in length, others that it can never exceed 500 or 700 feet.[2] Probably the truth lies somewhere between these two extremes. At any rate, it seems certain that thunderclouds never attain very high altitudes, probably not over 7,000 feet above the sea-level. On high mountains, thunder-clouds are seen below the observer ; and thus it would appear that while auroræ are chiefly, if not entirely, confined to the upper strata of the atmosphere, thunderstorms take place in the lower.

The magnetizing power of lightning must not be left unmentioned. After thunderstorms at sea, the action of the ship's compass has often been impaired. Occasionally the polarity of the needle is actually reversed, and often pieces of iron and steel become magnetic through the passage of lightning. Watch-springs have frequently suffered in this way, and after the remarkable storm, during which the church of St. George's, Leicester, was partially destroyed, described in the ensuing chapter, the iron cramps in the steeple and other masses of metal were found to be highly magnetized. These magnetizing effects are taken to indicate that the duration of lightning is, at any rate occasionally, considerably longer than is usually supposed, as magnetization is not momentary, but takes an appreciable time to accomplish.

Thunderstorms are not the only occasions of the manifestation of lightning. Violent volcanic eruptions are always accompanied by this, and sometimes by other electrical phenomena. Lightning seems to have been a specially marked feature of the terrible Krakatoa convulsion, nearly all eye-witnesses of the eruption laying stress upon this, as greatly adding to the horror and magnificence of the spectacle. Thus Captain Woolridge of the *Sir R. Sale*, viewing the volcano from the N. E. at sunset on Sunday evening, 26th May, describes the sky as presenting "a most terrible appearance, the dense mass of clouds being covered with a murky tinge with fierce flashes of lightning. At 7 P. M., when the dense vapor and dust clouds rendered it intensely dark, the whole scene was lighted up from time to time by the electrical discharges, and at one time the cloud above the mountain presented the appearance of an immense pine tree, with the stem and branches formed with volcanic lightning."[3] The same observer,

[1] "The Thunderstorm," p. 130.

[2] See discussion on lightning-rods at the meeting of the British Association, 1888.

[3] "Official Report of the Royal Society on the Eruption of Krakatoa," p. 19.

at a distance of forty miles, speaks of the great vapor cloud looking like "an immense wall, with bursts of forked lightning, at times like huge serpents, rushing through the air." Another observer, whose vessel was situated about forty or fifty English miles N. W. of the volcano, records that "lightning struck the mainmast conductor five or six times," and also that "the mud rain covering the masts, rigging and decks was phosphorescent; the rigging presenting the appearance of St. Elmo's fire."

"This abundant generation of atmospheric electricity," writes Professor Judd, "is a familiar phenomenon in all volcanic eruptions on a grand scale. Steam jets rushing through the orifices of the earth's crust constitute an enormous hydro-electric engine; and the friction of ejected materials striking against one another in their ascent and descent also does much in the way of generating electricity."[1]

CHAPTER VII.

ATMOSPHERIC ELECTRICITY CONTINUED.

DANGERS TO BE APPREHENDED FROM LIGHTNING—MODES OF PROTECTION.

Danger to life and property from lightning—Instances of loss of animal life—Death not inevitable from a "stroke" of lightning—Persons struck do not see the flash—Instance—Globular lightning is seen—Case of Mr. Pitcairn—Injury to buildings—Account of the partial destruction of St. George's Church, Leicester—Dangers formerly encountered at sea during thunderstorms—Examples—Explosion of gunpowder magazines by lightning—Earliest lightning conductors—Their inefficiency—System of protection devised by Sir W. Snow Harris—Directions concerning lightning-rods—Modern modifications—Real use of lightning-rods—Perfect system of protection not yet attained—Necessity of employing experienced electricians to erect lightning-rods—Protection of individuals from lightning—Metal does not "attract" lightning—Theory of an "area of protection" exploded—The most elevated objects not always those struck—Reason.

THE dangers to be apprehended from lightning are, in the case of property, destruction by fire, or by the extraordinary explosive powers sometimes manifested; and in the case of man and the lower animals, severe injury or death, owing to the shock to the nervous system,[2] caused by the passage through a living body of

[1] "Official Report of the Royal Society on the Eruption of Krakatoa," p. [illegible]

[2] This was until recently the reason assigned for death from lightning, or ...

electricity in such large quantities and at such high potential. Timid persons are often ridiculed for the terror they show during thunderstorms. There is, however, something to be said in their defence, for though all storms are not dangerous there is no doubt that some are so in a high degree, and, moreover, the disturbed electrical condition of the atmosphere before and during a heavy storm is of itself sufficient to induce great nervous discomfort in sensitive organizations. Accidents due to lightning are now made so public, owing to the newspapers which flood the civilized world, that they perhaps appear more frequent than they really are; but it is only necessary to remember the large number of thunderstorms which annually take place in the United Kingdom, and the small average of deaths either of men or animals occasioned by them, to feel reassured on this point. Before the introduction and better understanding of lightning-rods, indeed, high isolated buildings, particularly churches, were only too often "struck," and ships also suffered terribly; but in our days such occurrences are comparatively rare, and it is to be hoped that with the further advance of electrical knowledge they will cease altogether.

Before entering on the subject of protection from lightning, it may be interesting to give a few examples of the terrible destruction it may work. First with regard to animal life. In 1858 twenty-five sheep were killed during a thunderstorm near Abingdon.[1] In the same year, at Sacco, in Italy, on the 17th of August, 120 sheep out of a flock of 140 were killed by lightning. The shepherd and the shepherd's boy were not injured, though the latter was carrying a kid in his arms, which was killed.[2] This remarkable escape of human beings, when animals close by them are struck, is not unusual, and would seem to point to the conclusion that the lower animals are more susceptible than man to injuries from lightning. In some instances this could be accounted for by the greater propensity of animals to huddle together in groups, especially when terror-stricken. During thunderstorms such a tendency is dangerous, because the column of heated air rising from their bodies offers a good conducting path to the electric discharge. No such cause, however, could have accounted for the death of the kid in the shepherd boy's arms and the escape of the boy himself. When human beings are struck and recover (for to be struck by lightning by no means necessarily entails death), they invariably say they did not see the flash which rendered them unconscious. Many instances of this are cited in "The Thunderstorm," to which work frequent reference has already been made. A relative of the

powerful electric "shock." It appears, however, according to the latest investigations, that some direct effect is produced upon the heart, and that is most likely the immediate cause of death.

[1] "The Thunderstorm," p. 163.

[2] *Ibid.*, p.

present writer, who was struck by a flash of lightning during a violent thunderstorm in Yorkshire in 1886, saw nothing, neither did his wife, who was close to him and suffered, though slightly in comparison, from the effects of the same flash. More curiously, the woman in whose farm-house they had taken temporary refuge, and who was in another room, saw no flash either at this moment, but heard a sudden, sharp explosion, which she took for the report of a gun, and rushed in a state of great anger to demand an explanation from her guests, when, to her astonishment, she found one of them in an unconscious and apparently dying state. A short time sufficed to restore his senses, and no other injury was sustained beyond a shock to the nervous system, which for a time affected the general health and spirits, but not in any serious or incapacitating manner.[1] Globular lightning, whose movements are so much slower, is not thus invisible to those whom it injures. M. Planté cites an instance of a ball of fire the size of a fist, which, during a violent thunderstorm, appeared to two clergymen, Messrs. Wainhouse and Pitcairn, who were together in a room in the rectory of Steeple-Ashton, Wiltshire. It seemed to be one foot distant from them, and about the height of a man from the ground, and was surrounded by a dark smoke. Its explosion was attended by a noise comparable to the firing of several cannons and a strong "sulphurous" smell filled the house immediately afterward. Mr. Pitcairn was dangerously wounded.[2]

With regard to buildings, churches and any high or isolated erections are most exposed to danger from lightning. Mr. Tomlinson gives a formidable list of damages in "The Thunderstorm," occurring between the years 1822 and 1858, in which no fewer than thirty-three churches are included, and enters into many interesting details with regard to several of them. The most striking account is that of the injuries sustained by St. George's Church, Leicester, on 1st August, 1846, during a storm of quite exceptional violence and duration, and in which the phenomenon of globular lightning repeatedly presented itself. The storm had already been raging for hours, accompanied by

[1] One of the curious tree-like marks which have often been noticed on the bodies of persons struck by lightning was produced in this instance, and remained for a considerable time. It extended over the lower ribs on the right side, and resembled the trunks of two trees close together, with branches ramifying from them. The sufferer on this occasion also said that though he did not see the lightning he heard the thunder; in fact, it was the last thing he remembered before losing consciousness.

[2] "Phénomènes électriques de l'Atmosphére," p. 221. In a previous portion of this work M. Planté justly remarks "that it is not a small mass of air rarified and rendered luminous by the passage of an electric current which could thus explode with ...ler and resolve itself into 'strokes' of lightning. The source of this ...s in the reservoir of electricity contained in the thundercloud, which ...he point where the first escape began in the form of a ball of

torrents of rain, when "at five minutes past eight, after one or two peals of unusual distinctness, the Church of St. George was struck with a report resembling the discharge of cannon, and with a concussion of the air which shook the neighboring houses and extinguished a lamp burning at the entrance of the news-room, many hundred feet distant. . . . Two of the spectators of this awful event were Captain Jackson and the Rev. R. Burnaby, rector of the parish, who both described the flash as a vivid stream of light, followed by a red and globular mass of fire, and darting obliquely from the North-west with immense velocity against the upper part of the spire. For the distance of 40 feet on the eastern side and nearly 70 on the west, the massive stonework of the spire was instantly rent asunder and laid in ruins. Large blocks of stone were hurled in all directions, broken into small fragments, and in some cases, as there is every reason to believe, reduced to powder. One fragment of considerable size was hurled against the window of a house 300 feet distant, shattering to pieces the woodwork, as well as fourteen out of the sixteen panes of glass. . . . It has been computed that a hundred tons of stone were on this occasion blown to a distance of 30 feet in three seconds. In addition to the shivering of the spire, the pinnacles at the angles of the tower were all more or less damaged, the flying buttresses cracked through and violently shaken, many of the open battlements at the base of the spire knocked away, the roof of the church completely riddled, the roofs of the side entrances destroyed, and the stone staircases of the gallery shattered. The top of the spire, when left without support beneath, fell perpendicularly downwards inside the steeple, causing much devastation in its descent." [1]

The scene of this fearful accident [2] was afterwards minutely examined, when it became evident that the formidable explosions which worked the destruction were caused by the electric discharge on its road to the earth, bursting its way from one good conducting point to another through masses of badly conducting material. Thus we are told that "after traversing the vane and spindle, and the terminating iron supports, the only path left for the fluid was through a series of iron cramps, *separated by means of sand-stone; and here it was that the explosion commenced*, the stone being torn and hurled aside as it came in the path of the lightning to the lowest lead lights of the spire." [3]

[1] "The Thunderstorm," p. 153 ff.

[2] One almost equally severe appears to have occurred at Louvain on April 8 of the present year, 1890. The cathedral was struck by lightning. "One of the turrets was completely destroyed, and the top, weighing about four tons, was projected a distance of twenty-two yards, demolishing a house, while blocks of stone weighing from two to three tons were hurled a distance of nearly seventy yards, damaging the houses in the neighborhood."—*The Electrician* for June 6, 1890, p. 109.

[3] "The Thunderstorm," p. 156. Apparently this church was unprotected by any lightning conductors whatever.

In this accident, terrible as it was, no life was sacrificed, but M. Planté cites an account of a violent storm which took place on the 27th of July, 1769, during which several hundred persons, being congregated in a large public hall, suddenly saw a fiery globe the size of a large cannon-ball appear through an opening in the roof. All the lights immediately went out, and more than seventy-six persons were killed or wounded.[1]

However fearful the destruction worked by lightning inland may sometimes have been, ships were formerly exposed to a far greater degree of danger from this source. Isolated objects on the vast plain of the ocean, it was almost impossible that during thunder-storms they could escape being made part of the path of an electric discharge between the clouds and the sea, and the wonder is rather that so many escaped than that so many were "struck." Neverthleless, the destruction both of life and property before Sir William Snow Harris devised an efficient system of protection, was truly appalling. The accidents to H.M. ships alone between the years 1790 and 1840 numbered 280, some exceedingly serious; and the loss of life was proportionately great, 100 seamen having been killed, and 250 dangerously injured, while the monetary loss to the country was reckoned at £150,000.[2] Space forbids the citation of more than one instance, that of the Repulse, a 74-gun ship. On the 13th of April, 1810, the Repulse, being off the coast of Spain, was overtaken by "a heavy squall of wind, with rain, thunder and lightning, at which time the people were employed in getting down their washed clothes which hung from the rigging, when the ship was struck by two vivid flashes of lightning which shivered the maintop-gallant mast, and severely damaged the main-mast. Seven men were killed on the spot, three others only survived a few days, and ten were maimed for life. After the second discharge the rain fell in torrents; the ship was more completely crippled than if she had been in action, and the squadron, then engaged on a critical service, lost for a time one of its fastest and best ships."[3]

More terrible yet is the description of accidents which occur when lightning sets a ship on fire. Fearful stories of suffering and privation have thus been added to the roll of disasters at sea. Among others the case of the Tanjore, a ship belonging to the East India Company, is cited by Mr. Tomlinson. In May, 1820, she was struck by lightning forty miles off the coast of Ceylon; two men were instantly killed, and many others rendered insensible; the cargo, which was partly of brandy, caught fire, and burned so fiercely that the crew and passengers had to hurry into the boats without waiting even to take food and water. Fortunately a few ho[illegible] [illegible]y met with a native vessel and so were rescued.[4]

[1] "Phénomènes électriques de l'[illegible]

[2] "The Thunderstorm," p. 171 [illegible]

[4] *Ibid.* p. 182.

Many instances have occurred of powder magazines being struck and exploded by lightning. "In 1855, on the 7th of October, about 2 P. M., a firework manufactory in Green Street, Liverpool, was struck by lightning and blown up; the factory and the adjoining houses were destroyed, and many persons severely injured. . . . On the 10th of August, 1857, about midnight, lightning fell on the magazine of Joudpore, in the Bombay Presidency, whereby some thousands of maunds of gunpowder were blown up. Five hundred houses were destroyed, and nearly one thousand persons are reported to have been killed."[1]

Enough examples have now been quoted to show the need of protection from lightning, and it is time to turn our attention to the means employed for attaining this end. Lightning conductors were an almost immediate consequence of Franklin's famous experiment in 1752 (described on p. 33 of the present work), and only ten years later the first erected in England was put up by Dr. Watson at Paynsted. It is amusing to think that so little was the principle of their action understood, that during the war of Independence an animated discussion was carried on between the supporters of pointed lightning rods and those who recommended rounded tops. The matter was made a political question, the pointed rods being in favor with Franklin and the Revolutionary party, and the blunt with "loyal subjects and good citizens;"[2] neither side considering the scientific and practical question as to which was in reality the best protector, worth attending to. As a matter of fact, the pointed rods were, of course, preferable, points contributing to a silent and noiseless discharge, and round tops, on the contrary, being likely to cause an explosive discharge between the conductor and the cloud. In these early days, however, many other important matters beside that of points were but ill understood. One lightning rod stuck up anywhere, perhaps insulated at the bottom, instead of having a good earth connection, or run into a small stone tank of water, or into any other equally impossible place according to the better-instructed ideas of the present day, was deemed sufficient. Ships also were provided with a chain conductor of very small dimensions, stowed away in a box, and taken out to be suspended from the masts if occasion required. It is not surprising that such protection as this was found terribly inadequate, and that great danger was incurred by the sailors, through having to place these conductors in position during a storm. To Sir William Snow Harris belongs the honor of having first devised a really adequate system of protection both for buildings and ships. He insisted upon an unbroken line of metallic connection between every part of the building or vessel and the lightning rods as indispensable. Isolated masses of metal forming an

[1] "The Thunderstorm," p 169.

[2] *Ibid.*, p. 223, note.

integral part of any erection are fraught with danger, and exceedingly likely to cause such destructive explosions as those which occurred in the case of St. George's Church, Leicester, cited above—for the lightning in leaping from one conducting point to another will shatter the badly-conducting substances obstructing its path. The upright rod or rods should be armed with one or more points, and should project above those portions of the building to which they are attached. They should also have a thoroughly good earth connection, *i. e.*, the earth about them should be kept damp, and they should not be buried in charcoal, or beds of stone or rubble, nor led into inclosed tanks.[1] Running water, on the contrary, is excellent, as it affords a thoroughly good conducting channel for the electric discharge.

Lightning rods should also have a good extent of surface, but they need not, as was formerly thought, be solid. Hollow rods are quite as good, and flat ribbons, or a bundle of separate strands of thickish wire, better still. The solid rods were used under the idea that they offered a greater amount of conducting material to the passage of the electric discharge, because currents of electricity (and a discharge is a momentary current) penetrate the substance of conductors, and do not remain on the surface like static charges; but this only holds good of steady currents, not of sudden rushes of electricity like the discharge of a Leyden jar and lightning. In these cases the velocity is so great and the duration so short that the electricity scarcely penetrates below the surface, and therefore the important matter is that the latter should be of sufficient extent, not that the conductor should be solid. A modification has also arisen in the views held as to the best metal to employ in the construction of lightning rods. Until recently, copper was recommended by all electricians on account of its high conducting power, but it appears now that for this very reason it may be less suitable than iron, because, as Dr. Oliver Lodge stated in a lecture delivered before the Society of Arts on March 17, 1888, "If a great weight or a large reservoir of water were propped up above one's house, one would not say that, the safe thing being to get it down as quickly as possible, it was advisable to break away the props, or to blow the bottom out of the reservoir; no, one would prefer to let it slide slowly and gradually down a well-resisting channel, so as to disperse the energy gradually."

These words "to disperse the energy gradually" recall a consideration of the highest importance, which must never be lost sight of in any system of protection from lightning. The [illegible] at issue is not only—or even mainly—how to cond[illegible] of electricity safely and quietly into the e[illegible] of the

[1] It is specially recommended also that [illegible] the earth, not too near the surface.

enormous energy developed by lightning, which can neither be ignored nor conjured out of existence. Therefore, a certain amount of resistance may be a good thing as affording work to do to overcome it; but it need hardly be said that it should never be sufficient to occasion great heating, as that at once entails the danger of fire, or the collapse of the conductor through fusion, either throughout its length, or at special points, such as the joints, where increase of resistance is encountered.

Even with every precaution taken, and a system of protection from lightning adopted in accordance with the best practical electrical experience of the day, absolute safety cannot be guaranteed, as was abundantly proved by the Hotel de Ville at Brussels, which is protected by a most elaborate and carefully carried out system of lightning conductors, having been struck by lightning, and a portion set on fire in the month of June, 1888. But little damage was done, as the fire was almost immediately extinguished. Nevertheless, the case is a most important and instructive one, showing, as it does, that protection from lightning, though vastly improved, is not even yet perfectly understood. One of our leading electricians distinguishes between two main cases of lightning flash, the one caused by a steadily increasing strain between a cloud and the earth, so that the path of the flash is inductively prepared beforehand; the other by a sudden rise of potential in a cloud, between which and the earth no strain previously existed, by the discharge of another cloud into it, so that an "impulsive rush" of electricity takes place to the earth without any previous preparation. He considers that in the first of these cases, a system of protection carried out according to present ideas would be efficient, but not in the second case, and his conclusions are based upon a number of interesting and highly instructive original experiments.[1]

The foregoing remarks, though giving the merest outline of the subject, may nevertheless enable the general reader to understand something of its importance, and will at any rate serve to show him that the protection of a building from lightning cannot possibly be properly accomplished by any but practical electricians. A village workman must not be depended on for the erection of lightning-rods. It may perhaps be of interest to mention that in the case of gunpowder magazines and other stores of explosive material, high pointed conductors are not recommended. It must always be remembered that owing to the facilities they offer, they are likely, if present in sufficient numbers and at a sufficient altitude, to determine

[1] See Mann Lectures before the Society of Arts by Dr. Oliver Lodge, F. R. S., in March, 1888; also a paper by the same author on "Lightning, Lightning Conductors, and Lightning Protectors," read before the Institution of Electrical Engineers in April, 1889, reported in *The Electrician* of 3d May, 1889.

a discharge, which might not otherwise take place, between a cloud and the earth; and though in ordinary cases this would not be a source of danger, it certainly would where gunpowder or other explosive substances are concerned, as the smallest side spark (such as frequently takes place from lightning-rods to other conductors in close proximity) might cause a terrible accident. A network of iron entirely covering the edifice, or, better still, making the erection itself of iron, is far preferable in such cases.[1]

With respect to the protection of individuals from lightning, a few plain directions may be given. It is a well-known source of danger to stand close under trees or under any high and isolated object. Detached pieces of metal worn about the person should also be avoided, as well as standing near a fireplace if there is a fire burning. It is of no use to cover oneself with silk garments, or in fact to attempt insulation in any way, as this only increases danger. On the other hand, the rather impossible protection of a suit of armor would render its wearer perfectly safe so long as the joints did not become overheated, which might perhaps occur if the armor were actually struck. Such a defence, however, though excellent for the owner, would be exceedingly dangerous to his friends, for to touch it during the progress of a storm would ensure a violent, possibly fatal shock; and the same remark applies to iron network over houses and other erections. The building thus enclosed and all its inmates would be perfectly safe, but any one approaching it from the outside during a storm, and laying his hand upon the metal, would certainly rue the consequences.

It must not be supposed, however, that there is anything in metal which attracts lightning. Such is not the case. On account of its high conducting power it offers an easy path to the electric discharge, of which the latter will, if possible, avail itself; but it will not go out of its way to pick out a lightning-rod or any other metallic conductor. Instances have occurred of lightning striking buildings in close

[1] Telegraphic and telephonic instruments and stations require special protection from lightning, and the guards with which they are provided are almost always constructed on the principle that owing to the "impedance" offered by good conductors to a sudden flash (due to the oscillatory nature of the latter) it would rather jump over a short air-space than follow a length of wire. Double combs are used as protectors in telephone exchanges; a pair of plates separated by a very short space in telegraphic offices. These do not always prove efficient, however, and Dr. Oliver Lodge has devised a new lightning guard, for which he claims almost absolute perfection, and whose principle, in his own words, consists in taking "the overflow from one protector and giving it the chance of another; then taking the overflow from this and offering it another air-gap, and so on till nothing is left; at the same time diminishing the overflow from each protector as much as possible by the use of self-induction coils, which impede the violently varying or alternating rushes by their electromagnetic inertia."—Quoted from a paper read before the Institution of Electrical Engineers on 24th April, 1890, published in *The Electrician* for 23d May.

proximity to lightning-rods, erected under the idea that they would afford an "area of protection," within the limits of which nothing but themselves could be struck. This erroneous theory of an "area of protection" is fast dying out, as also that of the most elevated objects being always the ones struck. Very many instances are on record of houses in the immediate neighorhood of tall trees suffering from lightning, while the trees themselves escaped; and this, though apparently surprising at first, ceases to be so when we remember that the state of strain to which all the phenomena of discharge are due does not exist primarily between a cloud and the lightning-rod, tree, or steeple, or whatever the elevated object may be, but between the cloud and the whole of that portion of the earth's surface lying beneath it; therefore, all that these isolated and, in comparison to the extent of surface, small elevations can do, if they are good conductors, is to protect themselves from danger by rendering that part of the discharge which is taking place between them and the cloud harmless. They cannot do more than this, and hence the paramount importance of a metallic connection between every part of the building to be protected and its lightning-rods. During the discussion on lightning-rods which took place between Sections A and G, at the meeting of the British Association in Bath, 1888, a most remarkable photograph of a flash which occurred during a storm in America was shown. It can only be described by saying that the sky seemed to be literally pouring down the electric fire on every side, and the remark was justly made by its exhibitor,[1] "Where in such a case could the 'area of protection' be?" The only real safety would lie in the whole surface upon which this enormous quantity of electricity was descending being of good conducting matter; and in the presence of such tremendous manifestations of natural energy as this, we can but feel that though it behooves us to take every precaution which the most advanced science recommends, our preservation depends on a Higher Power and a Vaster Knowledge than any which our resources can command.

[1] The Hon. Ralph Abercrombie, F.R.S.

MAGNETISM.

PART II.

CHAPTER I.

GENERAL PROPERTIES OF MAGNETS.

Ancient knowledge of natural magnets—Lodestone an ore of iron—Made useful in navigation in the twelfth century—Gilbert's discovery of magnetic poles—Attraction between unlike and repulsion between like magnetic poles—The earth a magnet—Naming of the poles—Magnetic substances—Dia-magnetic substances—Action and re-action between magnets and magnetic substances equal—Similarities and dissimilarities between electric and magnetic induction—Magnetic induction cannot take place across magnetic substances—Acts across a vacuum—Various ways of making magnets—Consequent poles—Bar and horse-shoe magnets—Magnetic shell—Strength and lifting-power of magnet—Causes of loss of magnetization—Sub-division of magnets—Molecular theory of magnetism.

NATURAL magnets were known from very ancient times, and their name is derived from Magnesia, in Asia Minor, where many of the hard black stones possessing the property of attracting iron and steel were found. The English name of lodestone means simply leading stone. It is an ore of iron, called by mineralogists *magnetite*, and exists in large quantities in Sweden, Spain, and various other countries; though it by no means always possesses magnetic properties, being often found entirely destitute of them; nor is it known by what means they are acquired by those specimens of the ore which exhibit them. About the twelfth century it became known in Europe that lodestones, whose power of attracting iron was already attributed to magic, possessed another yet more marvelous peculiarity, viz., that of setting themselves always in a North and South direction when freely suspended. This property was made useful in navigation; and in fact the name lodestone is derived from the fact of the magnet stones being able to act as mariners' guides. The first artificial magnets were made by rubbing iron or steel with lodestone, when it was found that the latter imparted its magnetic properties to

these substances—the iron, however, only retaining its magnetism for a very short time; whereas the steel, though not able to be so powerfully magnetized as iron, did not again lose the properties it had acquired, but became a permanent magnet. Other ways of making artificial magnets, which will be mentioned in due course, are now known and extensively used.

Dr. Gilbert, whose electrical discoveries have already been mentioned, made many of equal importance respecting magnets, and in his work "De Magnete" described a number of elementary facts regarding them. He was the first to notice that the attractive power appears to reside at the two ends of a magnet, called always its *poles*.[1] This fact can easily be proved by placing an ordinary bar magnet among a number of iron filings, which will be seen to arrange themselves in thick tufts round the poles, thinning as the centre is approached, while at the actual centre there are none. This non-attractive part of the magnet Gilbert named the *equator*, and the imaginary line joining the poles, the *axis*.

It has already been mentioned that a freely-suspended magnet sets itself in a particular direction with regard to the earth, viz., with one pole pointing nearly North, and the other nearly South; moreover, it is always the *same* pole which points in the *same* direction; for if a magnet be turned by any means out of its natural position with regard to the earth, it will return to it again the moment the constraining force ceases, the pole which was before pointing North resuming the same direction. Let it now be supposed that there are two magnets the North-seeking poles of which have both been marked. One of these magnets is freely suspended (or balanced upon a pivot, which comes to the same thing), the other being held in the hand. The free magnet will, of course, be turned into its usual North and South direction; and this being so, let its North-seeking pole be approached to the North-seeking pole of the second magnet, when it will be seen that the former is instantly turned away from the latter, thus showing that *two North-seeking poles repel each other*.

Let us now vary the experiment by approaching the South-seeking pole of the magnet held in the hand to the North-seeking pole of the free magnet. We shall find that the latter will turn *toward* the South-seeking pole, and, if near enough, will rush into contact with it, thus remaining till the two are separated by force, showing that a *North-seeking and a South-seeking pole attract each other*.

It would appear, therefore, that as there are two kinds of electricity, positive and negative, so there are two kinds of magnetism, North-seeking and South-seeking. Moreover, since it is evident from the

[1] It is only in a long, thin bar magnet that the poles are actually situated at the extreme ends, however. In thicker magnets they lie slightly nearer the centre.

position taken up by a magnet with regard to the earth that the North part of the latter attracts one pole of the magnet and the South part the other, and since only magnets have this power of attraction and repulsion over other magnets, we are driven to the conclusion that the earth itself must be a magnet obeying the invariable law that *like poles repel and unlike poles attract each other*, and that this is the reason of the North and South direction taken up by a freely suspended magnet, whose North-seeking pole points to the South magnetic pole of the earth, and its South-seeking pole to the earth's North magnetic pole. It is usual and more convenient to employ, instead of a magnet, a magnetic needle for experimental purposes. The needle is made of steel and is very light and thin, usually lozenge-shaped, and balanced on a pivot in the manner of that used in the ordinary pocket compass. It is magnetized by being rubbed with a magnet; and has, of course, a North-seeking and South-seeking pole. These are in common parlance called the North and South Poles, at least in England; but the custom leads to very great confusion of ideas; for if we name that pole of the magnetic needle pointing toward the North magnetic pole of the earth the North Pole, and that pointing toward the South magnetic pole the South Pole, we virtually state that like poles attract each other, which is the very reverse of the fact, and consequently the terms North-*seeking* and South-*seeking* which have frequently been adopted by English men of science are far more correct, and will be used in the present work.

A magnet always has two poles, one North-seeking and one South-seeking; it is quite impossible to obtain a magnet with one pole only; but a *magnetic substance*, viz., a substance which, like iron, has the power of attracting and being attracted by a magnet, has no poles, neither does it appear to have any force of repulsion, for it is equally drawn to either pole of the magnet which may be presented to it. Iron and steel are not the only magnetic substances; nickel and cobalt show the same properties, but in a very inferior degree; and some other metals, as well as paper, porcelain, and oxygen gas, are feebly attracted if exposed to the influence of a very powerful magnet.

It was for a long time supposed that those substances not attracted by a magnet were not influenced by it at all; but experiment has proved that if subjected to strong magnetic action they are repelled, or at least appear to be so. Bismuth possesses this property in the most marked degree, and a small bar of bismuth suspended between the poles of two powerful magnets,[1] turns itself so as to lie at right angles to the line between the poles, thus getting as far away from them as possible.[2] A bar of iron or steel suspended in the same

[1] Electro-magnets, which will be described in a future chapter, are employed in these experiments.

[2] This behavior of the bismuth and of other dia-magnetic substances has, however,

manner would, on the contrary, turn along this line so as to present its ends to the poles, thus approaching them as closely as it could. Substances which appear to be repelled by magnets are called *dia-magnetic.*[1]

By *magnetic force* is meant the force with which a magnet attracts or repels another magnet, or with which it attracts a piece of iron, or of any magnetic substance. This force decreases with distance, and between two magnet poles it is directly proportional to their strength, and, if they are very small and far apart, inversely proportional to the square of the distance between them.

It is easily understood that the attraction between two unlike magnet poles is mutual. Each is drawn toward the other; but perhaps it is not quite so evident that the attraction between a magnet and a magnetic substance, a lump of iron for instance, is also mutual. At any rate, the popular idea is that the magnet attracts the iron, but we do not hear of the iron attracting the magnet. Yet this is equally true; for if a magnet be balanced on a piece of cork and set floating in a basin of water, and a lump of iron be held near the edge of the basin, the magnet will immediately move toward it, just as we should see the iron move toward the magnet if their positions were reversed. Moreover, the action and reaction between a magnet and a magnetic substance are equal, just as the action and reaction between two magnets are equal. The fact is that a magnetic substance is one in which a magnet can induce temporary or permanent magnetism of the opposite kind to that of the pole presented to it, and this is the cause of the mutual attraction.

Magnetic induction can only take place in magnetic substances, just as electric induction can only take place in conductors; and here we may remark on the great likeness existing between some of the fundamental phenomena of electricity and magnetism. Electrified bodies can attract and can repel; so can magnets. Electrified bodies can induce electricity in other bodies; magnets in like manner can induce magnetism. Yet, though there are great similarities, there are also great differences. An electrified body has no poles; its power of attraction and repulsion resides all over its surface. Moreover, an electrified body electrifying another by contact, electrifies it in the same way as itself, and parts with some of its own original charge to do so. A magnet behaves quite differently; its poles always magnetize in the opposite way to their own magnetism, whether by contact or by influence, and no magnet ever loses any of its magnetism

been shown to be due, not to their being really repelled, but urged into the weakest part of the magnetic field. Substances which are faintly magnetic behave as though they were dia-magnetic if immersed in a medium more magnetic than themselves.

[1] Thus named because they allow the magnetic forces to act across them, which "magnetic" or, as they are often called, "para-magnetic" substances will not do.

by imparting it to another body. It remains quite as powerful after as before the operation. Neither can it be said that magnetism and stationary electric charges show the slightest relationship to one another,[1] though, as we shall hereafter see, electric *currents* and magnetism appear to be very closely connected, indeed; and since current and static electricity have been proved to be the same agent manifesting itself under different conditions, we may justly infer that magnetism is not of a wholly different nature from either.

Magnetic induction will take place through any substance, provided it be not itself magnetic. A magnet enclosed in glass or wood, or immersed in water, will equally exert its power of attraction and repulsion. But it cannot do this across thick iron, and a magnet placed within a thick hollow iron ball is incapable of influencing or being influenced by any outside magnet. The reason of this would appear to be that the action and reaction between the magnet and the iron employ the whole magnetic force of both, and therefore none can penetrate beyond the iron. Magnetic induction can take place across a vacuum, thus showing that the presence of ordinary matter is not necessary to the transmission of the magnetic forces, and that the real medium by which they are conveyed is the ether.

As has already been stated, there are various ways of making magnets. The simplest, but not the best, is by stroking the bar or needle of steel to be magnetized from end to end with a lodestone or steel magnet. This is called magnetization by single touch. Another and better way is to use two magnets, commencing by placing their opposite poles together in the centre of the bar to be magnetized (which is laid in a horizontal position), and then drawing them along to the ends, repeating the operation several times over. This is called magnetization by divided touch. *Both* sides of the bar should be subjected to the same treatment, and care taken that it is methodically and regularly followed out; otherwise there may be points between the true poles where other poles will be formed, called *consequent poles*, thus weakening the external influence of the magnet through the reaction of the consequent poles on each other. Magnets can be made by the action of the earth's magnetism on bars of steel held in the magnetic meridian, *i.e.*, with one end directed towards the magnetic North, and the other toward the magnetic South Pole of the earth, and struck by a wooden mallet while in this position. A bar of steel raised to a red heat, and allowed to cool while lying in the magnetic meridian, also acquires magnetic properties; but by far the most powerful magnets are made by placing a bar of steel or iron inside a coil of wire through which an electric current is caused to pass. The steel is made into a permanent magnet by this operation,

[1] It appears that if a magnet and a charged body are in relative motion, a very slight inter-action occurs, tending to make them revolve round each other.

but the soft iron only retains the whole of its magnetic properties while the current is passing. During this time, however, it becomes magnetized to a very high degree, indeed; and these electro-magnets, as they are called, are by far the most powerful of any, and will be described and explained in a later chapter. Magnets which have been magnetized to the highest degree of which they are capable, are said to be *saturated*.

A magnet can be made of any shape, but the bar and and the horse-shoe are the most common. Instead of a bar a bundle of steel wires may be magnetized, and will act as one magnet. These *laminated magnets* are stronger than single bars, provided the wires be magnetized separately before being put together. A thin sheet of metal may be so magnetized that the whole of one face of it will possess North-seeking, and the whole of the opposite face South-seeking magnetism. Such an arrangement is called a magnetic shell, and is of considerable interest and importance, because it in many respects greatly resembles a closed voltaic circuit.

By the *strength* of a magnet is meant the amount of magnetic force it possesses, *i. e.*, the power of attraction and repulsion shown by its poles; but the *lifting power* of a magnet is a different thing. It signifies the weight which a magnet is able to support, and that depends on the surfaces of contact as well as on the strength of the magnet. A horse-shoe magnet has much more lifting power than a bar magnet, for the simple reason that both its poles are pressed into the service, whereas with a bar magnet one only can be employed for this purpose.

Though steel once magnetized becomes so permanently, as we have seen, there are, nevertheless, circumstances under which it cannot retain its magnetic properties. They are weakened if the steel is very much heated, though partially recovered as it cools, and lost altogether if it is made red hot. If the ordinary temperature of a steel magnet is lowered, on the contrary, its strength increases, unless the cold to which it is subjected be very extreme, indeed, when it loses its magnetization.[1] The same thing happens if it is roughly used and knocked about; and this seems to point to the conclusion that magnetism is closely connected with molecular structure. A far more convincing testimony is borne to this theory, however, by the effect of rupture on a magnet. The latter appears, as has been stated, to have no magnetic force at its centre. Nevertheless, if a magnet is broken in half, each half will be a perfect magnet with a North-seeking and a South-seeking pole; and if the halves be broken in their turn, four perfect magnets will have taken the place of the single original one. In fact, the process may be repeated indefinitely; and if the single magnet were to

[1] Professor Silvanus Thompson states that a steel magnet brought down to a temperature of 100° C. below zero loses its magnetic properties.—"Elementary Lessons in Electricity and Magnetism," p. 84.

be broken a hundred or a thousand times, each piece, however small, would still be a perfect magnet.

Only one theory has been put forward which seems to give a satisfactory explanation of this phenomenon. This is, that every molecule contained in a magnet is itself an infinitesimal magnet with a North-seeking and a South-seeking pole, and that the state of magnetization consists in all the molecules being turned the same way—set end to end as it were—so that the North-seeking poles all point in one direction, and the South-seeking poles in the opposite direction. The inevitable result of such an arrangement would be, that the magnetic force would always appear to lie at the ends of the magnet, and yet that it could be divided into any number of perfect magnets.

There are other phenomena besides those already mentioned which

FIG. 11.—Lines of force in a magnetic field formed by a single bar magnet.

support the molecular theory of magnetization. A bar of steel when magnetized slightly lengthens, thus showing that there is a change of arrangement in the molecules, and that it must be one which places them parallel to each other. Water rendered muddy by being mixed with fine magnetic oxide of iron becomes, when magnetized, clearer in the direction of magnetization, as though light were able to pass better by reason of the parallel arrangement. A metallic clink is also heard when iron is magnetized and demagnetized, and when this is rapidly done it becomes hot, showing that internal friction must take place.[1]

[1] Since the above was written, Professor Ewing has given, in a paper on magnetic induction, communicated to section A at the meeting of the British Association, at Leeds, 1890, an account of some highly interesting and important experiments, which appear to place the molecular theory of magnetization on a much firmer basis than has ever been the case before. It may, in fact, be said to be to a great extent proved.

The space all round a magnet, within which the magnetic forces make themselves felt, is called a *magnetic field*, and the directions along which these forces act have been called *lines of force*. Their shapes differ according to the number, position and shape of the magnets forming the field.

Figures of these lines of force are obtained by placing a sheet of paper over a magnet, and then sifting very fine iron filings through a muslin bag over the paper. They arrange themselves in beautiful curving lines, each particle taking up the position assigned to it by the combined action of both poles, so that at every point of the lines the resultant direction of the attractive and repulsive forces is accurately shown. Fig. 11 gives the curves of the lines of force in a magnetic field formed by a single bar magnet; Fig. 12 shows those

FIG. 12.—Lines of force in a magnetic field formed by two bar magnets, with North-seeking and South-seeking poles confronting each other.

FIG. 13.—Lines of force in a magnetic field formed by two bar magnets, with North-seeking poles confronting each other.

in a field containing two bar magnets with opposite poles confronting each other; Fig. 13 those where similar poles confront each other. These two last figures illustrate most strikingly the action of the attractive and repulsive forces. The lines from the opposite poles which attract each other, curve inward so as to enter the one pole from the other; the lines from the similar poles which repel each other curve outward, turning aside at right angles so as to get as far away as possible.

The size and strength of a magnetic field depend on the strength of the magnet or magnets contained in it, and on their position with regard to each other. The strength is always greatest near the poles. Any magnetic substance placed in the field becomes for the time magnetized by induction.

CHAPTER II.

MAGNETISM OF THE EARTH.

Gilbert discoverer of the earth's magnetism—Oscillations of magnetic needle before settling itself in the magnetic meridian—Magnetic intensity—Magnetic poles of the earth—Declination of the needle—Variations in the declination and their causes—Line of no variation—Isogonic lines—Inclination of the needle—Inclination compass—Magnetic equator—Isoclinic lines—Magnetic maps—Fluctuations in the earth's magnetism—Periodicity in the occurrence of magnetic storms—Influence of the sun on terrestrial magnetism—Effect of the earth's magnetic force on the magnetic needle, directive only—Magnetization of steel and iron objects by the earth—Magnetism of iron ships.

THE honor of first discovering that the earth itself is a large magnet belongs to the same Dr. Gilbert whose name has already been several times mentioned. As we have seen, a magnet or magnetic needle when freely suspended, *i. e.*, hung from, or balanced on the point, which is its centre of gravity, takes up a particular position with regard to the earth, turning itself so as to lie in the magnetic meridian. It does not do this with one steady movement, but undergoes a series of oscillations before finally reaching its position of equilibrium, and every time it is moved or disturbed the oscillations are repeated. By making calculations on the number which occur in one minute, the strength of the earth's magnetism, called its *magnetic force* or *intensity*, at the particular locality can be discovered; though it must be remembered that the weight, shape and length of the magnet have to be taken into account, the number of oscillations executed in a minute depending on them as well as on the strength of the earth's magnetism.

From the fact that the magnetic needle does not point due North and South, we may infer what is in fact actually known, that the earth's magnetic poles do not coincide with its geographical poles. The North magnetic pole is situated just within the Arctic Circle in Lat. 70° 5′ N., Long. 96° 46′ W. The South magnetic pole has never been discovered, and from various indications it is thought that there may be two. The angle made by the magnetic needle with the geographical meridian is called its *declination*, and this is continually varying. The North-seeking pole lies at present to the West in Europe and Africa, and to the East in Asia and the greater part of North and South America. Some of the variations in the declination of the needle take place gradually through a number of years, some annually and daily,[1] and some are the result of sudden electric and magnetic disturbances, such as displays of the Aurora Borealis,

[1] The daily variations follow the course of the sun, or, rather, seem to make an effort to do so, for they are very slight.

earthquakes and volcanic eruptions. Thunderstorms and ordinary atmospheric perturbations produce no such effect, however. These accidental variations in the declination of the needle are known as magnetic storms, and are sometimes very marked indeed. Magnetic storms are always attended by a display of the Aurora Borealis in Northern latitudes, and are sometimes simultaneous at widely distant places on the earth's surface.

There are certain parts of the earth where the magnetic North and South do actually coincide with the geographical North and South, and at these places there is no declination of the magnetic needle. They are connected by an imaginary line called a line of no declination, or *agonic line*, which passes round the earth, nearly from North to South, cutting the Equator at right angles. Besides the agonic line there are a number of other imaginary lines called *isogonic lines*. Each one of these connects places on the earth's surface where the declination is the same. A map drawn out representing the isogonic lines is called a declination map,[1] and is of great service to mariners, whose compass is in like manner called a declination compass. It is not known who was the first inventor of this valuable instrument, but it was in general use in Europe in the thirteenth century, though in a much more primitive form than any with which we are familiar. It consisted merely of a magnetic needle set floating in a basin of water by means of a cork or of two straws, and nothing then was understood about "declination;" the needle was supposed to point due North and South.[2] Hundreds of years before the compass was used in Europe, it was known to the Chinese, who navigated their ships by means of a magnetic needle pointing South, and it is even stated by Humboldt that 1000 years B. C. the Chinese had magnetic carriages in which to find their way across the plains of Tartary. The compass consisted of the figure of a man with a movable arm pointing to the South.

Beside setting itself in the magnetic meridian, there is another peculiarity to be remarked in a freely suspended magnetic needle, namely, that if placed in a horizontal position, its North-seeking pole dips downward in the Northern hemisphere, and its South-seeking pole in the Southern hemisphere. This fact was first discovered in 1576 by a scientific instrument maker named Norman, and he constructed an *inclination compass* or dip needle, designed to show the angle of dip or inclination which the magnetic needle makes with the horizon. Far more delicate and accurate instruments are now in use at Kew and other great observatories, where daily and minute records are kept of the three magnetic elements, as they are called, namely,

[1] That is to say, it is so called by scientists. Sailors know it as a "variation" map.

[2] Columbus is supposed to have been the first European to discover the declination of the magnetic needle.

the intensity of the earth's magnetism at the particular spot, and the declination and inclination of the needle.

Just as there are places where there is no declination, so there are places where there is no inclination, and these are situated at the farthest possible distance from the magnetic poles. The imaginary line which connects them, therefore, roughly follows the course of the geographical equator, cutting it at two points almost exactly opposite to each other, and situated one in the Atlantic and one in the Pacific Ocean. This line is called the *magnetic equator* or *aclinic line*. *Isoclinic lines* are those which connect places on the earth's surface where the inclination of the needle is the same. At the North magnetic

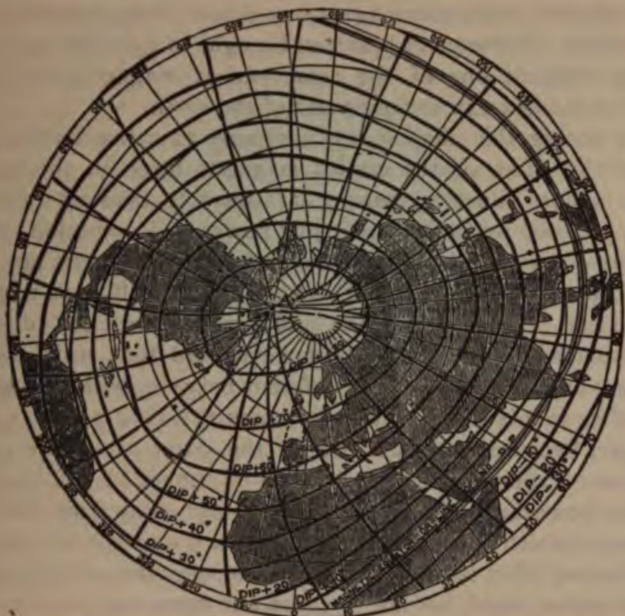

FIG. 14.—Magnetic Map of the Northern Hemisphere. A, North Magnetic Pole.

pole the inclination needle is vertical, and could the South magnetic pole be reached its position would, of course, be the same there. We have therefore very clear evidence that the magnetic force affecting the needle does really reside in the earth itself, and not at any point above its surface, for were this the case there would be no inclination. Fig. 14 is a magnetic map of the world showing both the isogonic and isoclinic lines of the Northern hemisphere. It is not possible, however, to construct such maps accurately once for all like geographical maps. The inclination, like the declination of the needle, undergoes annual and other variations; and in fact the minute and careful observations which have been made of late years show

that the magnetism of the earth is in as continual a state of fluctuation as the waters of the ocean.[1] Nevertheless, it is possible to determine what these fluctuations are likely to be for a few years in advance, and to construct maps which will hold good approximately for that length of time. The close study accorded to terrestrial magnetism has brought out many curious facts concerning it, one of which is a certain periodicity in the appearance of magnetic storms which makes their greatest frequency coincide with the maximum period of sun spots, *i. e.*, every ten or eleven years. It would seem, in fact, that there is some remarkable connection between the sun and the earth's magnetism. One specially striking proof of this occurred in 1851, when a luminous mass was seen to cross a sun spot, and at the same time the magnetic needle at Kew underwent great perturbations. Subsequent inquiries brought to light the fact that at the same moment one of the most violent magnetic storms ever known was going on in various parts of the earth.

Before closing this chapter it is necessary to call attention to the fact that the effect of the earth's magnetic force on the magnetic needle is simply directive, causing it always to take up a particular position, but not imparting to it any power of locomotion. This is proved by observing the behavior of a floating magnetic needle. It does not move toward the North, though it sets itself so as to point in that direction. Yet if we were to hold a magnet near the edge of the vessel, the needle would instantly move toward that, which seems to necessitate an explanation of its different behavior with regard to the earth. The fact is that in ordinary cases the needle moves toward the magnet because the nearer pole of the latter acts more strongly on one pole of the floating needle than on the other. In the case of the earth, however, both its poles are so far away from the needle that the one which is nearest exerts equal and opposite forces on the latter, forming what is called the *terrestrial magnetic couple*, tending to turn the needle round, but not to cause any movement of translation.[2]

It has already been stated that the earth is able to induce magnetism in steel or iron bars; but, in fact, any steel or iron objects, or masses of those metals, are affected in the same way. Fire-irons which have been allowed to stand for a considerable time in a vertical or inclined position become magnetized, the lower end being a North-seeking and the upper end a South-seeking pole;[3] and the same

[1] These fluctuations in the magnetism of the earth cause what are known as "earth currents," often very troublesome in telegraphy. They always occur during magnetic storms, and there are also exceedingly weak daily earth currents, flowing from the magnetic poles toward the equator.

[2] Any two equal forces acting in opposite parallel directions to each other, on a rigid body, tend to produce a movement of rotation.

[3] That is, in the Northern hemisphere. In the Southern the reverse would be the case.

remark applies to railings, lightning rods, etc. Objects made of steel or of cast iron retain this state of magnetization, but pure, soft iron cannot do this, as it possesses no *retentivity*, or *coercive force* as it is called. For this reason a bar of soft iron magnetized by the earth has the magnetism of its poles immediately reversed with the reversal of their position if it be tapped, that which was a North-seeking becoming a South-seeking pole if turned upward. This phenomenon is very rarely observed, however, in common objects, as the ordinary iron of commerce is not perfectly pure, and therefore possesses a slight retentivity, even the tools in a smith's shop showing faint signs of magnetization.

The most important effects produced in this way by the earth's magnetism are those on iron ships, which during the process of building become, owing to the hammering they receive while under the influence of the earth's magnetism, permanently magnetized, and consequently able to exert a disturbing influence on the compass needle, which is thus in many positions of the ship unable to lie in the true magnetic meridian. Such a result is of course disastrous to navigation, and various methods of obviating it are resorted to. The use of compensating magnets, *i. e.*, masses of iron placed in such a position with respect to the compass that they neutralize the effect of the ship's magnetism on it, is one; but here a difficulty arises from the fact that after a first voyage the magnetism of the ship generally alters, becoming less strong than it previously was, owing to the buffeting of the waves. In fact, for a considerable period every voyage makes a difference to the ship in this way, and the compensating magnets have to be frequently altered, lest they in their turn should disturb the compass needle by over-compensating the magnetism of the vessel. Fortunately, after a time this does become really fixed, but until then so great are the difficulties attending the use of compensating magnets that they are frequently dispensed with, and a table of errors drawn up by careful observation of the magnetism of the ship and continual comparison with the indications of the compass needle is trusted to instead. In the Royal Navy both methods are employed. The extreme importance of care in this respect is demonstrated by the fact that the loss of ships has been known to occur owing to errors in the compensating magnets which rendered the compass directions untrue. Such a disaster has, however, never occurred in the Royal Navy—a fact on which the authorities justly pride themselves.

Frequently a standard compass is placed in the masts, so that it may be as far removed as possible from the influence of the ship's magnetism.

CURRENT ELECTRICITY.

PART III.

CHAPTER I.

THE GALVANIC BATTERY.

Definition of an electric current—Direction of the current—Galvanic battery—Description of simple voltaic or galvanic cell—Effects of the current—Its cause—Poles — Electro-motive force — Resistance—Ohm's law — Difference between electro-motive force of cells in series and in parallel — Weakening of current through polarization—Daniell's cell—Grove's and Bunsen's batteries—Principle common to all batteries—Secondary batteries—Possibility of obtaining them due to polarization—Self-induction—"Extra-current" effects —Space surrounding wire conveys the electric current as well as the wire itself—Nature and effects of an electric current the same from whatever source it is supplied—Thermo-electric currents and the thermopile.

IT can hardly be said that in the section devoted to static electricity no mention was made of currents, for all discharge was shown to be a flow, and flow is but another word for current. That which takes place in discharge, however, is momentary, and by a current of electricity a *continuous* flow is nearly always understood. This continuous flow is caused by a maintained difference of potential between one point and another, and when once set up it does not cease until the potential is equalized, any more than a river would cease flowing unless its whole bed became level or its springs were dried up.

By the direction of an electric current is invariably meant *the flow from positive to negative*, though it must not be forgotten that there is always a negative current as well, whose course is exactly opposite, *i. e.*, from negative to positive. In practice this is usually entirely ignored, a fact which does not render it one whit the less important and interesting to those whose inquiries turn toward the nature of electricity. No satisfactory theory can be propounded which does not take into account the double current.

One of the easiest and most familiar ways of producing an electric

current is by means of the *Voltaic* or *Galvanic battery*, discovered toward the close of the last century by the researches of two eminent Italian scientists, Volta and Galvani, working independently of each other and on some theoretical points diametrically opposed.

A battery consists of a larger or smaller number of cells or "elements" exactly like each other, and the following is a description of the earliest form of cell. A strip of copper and a strip of zinc are placed, not touching each other, in a glass or porcelain vessel containing an acid liquid (a very weak solution of sulphuric acid is generally used), and are connected by copper wires, starting one from the zinc and the other from the copper plate (Fig. 15). When these wires are joined a current of electricity is set up which flows from zinc to copper through the liquid, and from copper to zinc through the wires, that is, right round the circuit, and it continues to flow thus till the wires are disconnected. The junction between the wire and the copper plate is called the positive pole or *electrode*, because it is there that the positive current *through the wires* begins, and the junction between the wire and the zinc plate is called the negative pole or electrode. This current produces all the same effects as a discharge. The magnetic needle is deflected by it, chemical decomposition is caused, a thin wire becomes heated, and if the ends of the two wires are placed on the tongue a peculiar taste is noticed. All these effects are greatly enhanced by placing a number of cells in series, connecting the zinc plate of one to the copper of the next, and so on, the wires being fixed to the terminal zinc plate at one end and the terminal copper plate at the other. When the cells are thus connected, the current flows from one to the other, but they may be arranged *in parallel*, *i. e.*, all the zinc plates connected to each other, and all the copper plates to each other. The current then divides itself between the cells.

FIG. 15.—Single Galvanic Cell, indicating the direction of the current through the liquid and wires. Z, zinc plate; C, copper plate. The terminal wires join Z to the copper plate of an adjoining cell, and C to the zinc plate of an adjoining cell.

At this point the question naturally arises, What causes the current? A long and fierce war, perhaps hardly yet terminated, was waged by the disciples of Volta and Galvani respecting the right answer to be given. The former maintained that the current was due to contact of dissimilar metals, the latter to chemical action; and since both these causes exist in the battery, and both produce difference of potential, which is as necessary to the existence of a current as difference of level is to a flow of water, it seems very difficult to decide between the two. Probably the right way of addressing the disputants would have

been in the words of the traveler called upon to arbitrate in the far-famed quarrel concerning the color of the chameleon,

"You both are right and both are wrong."

It probably is the contact of dissimilar metals which causes the difference of potential in the first instance, and the effort to maintain this potential difference requires chemical action, so that the chemical action, to be presently described, maintains the continuous flow.

The work done in a galvanic battery may be compared to the work done by a pump. The pump raises water from a low to a high level, in opposition to the natural tendency of water to flow from a high to a low level. Work is thus expended *on* the water which is reproduced, minus the amount wasted in friction in the pump, *by* the water as it flows back to its original level. In a galvanic battery electricity is raised from a low to a high potential in opposition to its apparent tendency to flow from a high to a low potential. Work is thus done *on* electricity which is reproduced, minus the amount wasted in overcoming the resistance of the battery cells, *by* electricity as it flows back through the outer circuit to its original potential. What happens *inside* the cells of a battery, then, is that an electric current is driven against a difference of potential (or of electric level), and that a difference of potential is consequently produced and maintained between the terminals or electrodes of the battery. What happens *outside* the battery is that a flow of electricity takes place between the terminal at high potential to that at low potential, so that the direction of the current is with the slope of potential, and work is done by it on its road. Electricity is raised from a low to a high potential inside the battery, and caused to flow from a high to a low potential in the same circuit outside the battery, by what is called *electro-motive force.* No electric current can exist anywhere without an electro-motive force; and since in very many instances it may also be said that no current can exist without a difference of potential, these two terms, electro-motive force and difference of potential, are often regarded as interchangeable. Yet they do not express the same thing. Electro-motive force may cause, or may be the result of, difference of potential, or may exist without it, whereas difference of potential can not exist without electro-motive force. Moreover, it is necessary to remember that though electro-motive *force* is thus named, it is not, accurately speaking, a force at all. It does not act on matter, which is the characteristic of force. It acts on electricity, whatever that may exactly mean. And perhaps the most comprehensive definition which can be given of it is, that it is "the ratio of the rate of doing work in the circuit to the current flowing."

It has already been stated that, however good the conductor through which an electric current is flowing may be, the latter always encounters a certain amount of obstruction or *resistance* on its road,

which may be considered analogous to friction in the case of ordinary matter. The power of the current to overcome this resistance depends on the force with which it is being driven along (on the electro-motive force); and the strength of the current, by which is meant the quantity of electricity flowing per second past a cross-section of the conductor conveying the current, increases in direct proportion to the increase of potential difference. It was ascertained first by Ohm, and has since been carefully proved by others, that in a metallic conductor of the same material, dimensions and temperature, the ratio of potential difference to current-strength never changes, and may be called the *resistance* of that particular conductor. This statement is known as *Ohm's law*, and has now been proved true for liquids. Its various applications are of the greatest importance and interest to practical electricians.

When the cells of a battery are connected in series, the sum of their respective electro-motive forces is the electro-motive force of the whole battery. When they are in parallel, the electro-motive force of one cell equals that of the battery. The electro-motive force of any cell is independent of its size, and is affected only by the materials of which it is made.

The current in the earlier batteries could only be maintained a short time, owing to the rapid decrease in its strength caused by the very chemical action which produced and sustained it. This chemical action consists in the dissolving of the zinc in the acid, by which means sulphate of zinc is formed and hydrogen gas set free. The latter forms in bubbles on the copper plate, and there does a two-fold mischief. In the first place, being a bad conductor, it greatly diminishes the effectiveness of the copper; in the second, being itself an electro-positive substance (becoming positively electrified by contact with other substances), it tends to set up an opposing electro-motive force in the battery; in other words, a second positive current flowing in an opposite direction to the first, and consequently much weakening its action. A battery in this condition is said to be polarized, and various cells have been made by different electricians to prevent its occurring, and so render the current [illegible] maintain the same strength for a long time together. Daniell's (Fig. 16) was the first [illegible]

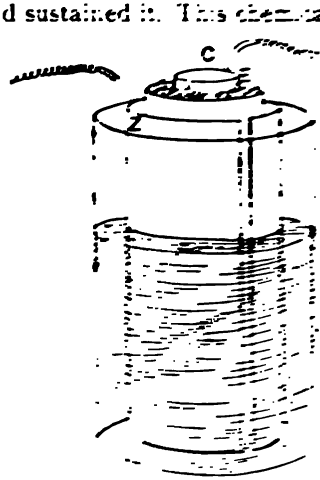

Fig. 16.—Daniell's Cell. [illegible]

are still much used. Instead of one, two liquids are employed in it, one in contact with the zinc, and one with the copper plate, which are sometimes rolled cylinder fashion, and divided by a porous, unglazed earthenware partition. The liquid, which is in contact with the copper plate, contains sulphate of copper as well as sulphuric acid. The effect of the whole arrangement is to intercept the hydrogen on its road, and instead of it particles of copper drawn from the sulphate of copper contained in the liquid are deposited on the copper plate, which, consequently, cannot lose in efficiency.

Another form of battery much used is Grove's, where platinum is substituted for copper. Though capable of maintaining a current of the same strength for several hours at a stretch, the expense of the platinum constitutes a disadvantage in this battery ; and Bunsen contrived one greatly used in laboratory experiments in which graphite, hard gas carbon obtained from the interior of gas-retorts, is used instead of either platinum or copper.

There are many other batteries unnecessary to describe here, their suitability varying with the purpose for which they are employed. One principle, however, is common to all. No battery can produce a current giving sensible effects unless there is a sensible consumption of its materials by chemical action, any more than a fire will give out sensible heat without a sensible consumption of coal. The material which is "burned" in a battery is generally zinc, which, being almost at the head of the electro-positive series (see p. 24) and very readily oxidisable,[1] has not hitherto been replaced by another less expensive substance. In consequence of this it was found impossible to utilize electric currents on a large scale in any work, such as electric lighting, where powerful currents were required, till some other method than that of galvanic batteries could be employed to generate them, for the consumption of material being proportional to the strength of the current, a large quantity of zinc must be used up in order to produce a powerful current for a considerable time. In telegraphy, where a weak current suffices, this objection does not apply. It should be mentioned that it is necessary to use either perfectly pure or amalgamated zinc, otherwise chemical action goes on, and the zinc dissolves even when the current is not passing, which "local action," as it is called, causes much needless waste.

Before quitting this subject, mention must be made of what are called *secondary batteries*, in which the energy of a current may be stored up as chemical work, and again given out in the form of electric energy. They are also called *storage batteries*, and an opinion is often held by the unscientific that electricity itself is stored. Such is not

[1] It is absolutely necessary that one of the metals employed in a battery should have a great affinity for oxygen, as it is this affinity which first starts the chemical action in the cells.

the case, however; it is the energy of the current which is stored in the form of the products of chemical decomposition, and when this stored-up energy is freed, an electric current is again set up and chemical recombination begins. A secondary battery cannot commence to work of itself. It needs in the first instance to be "charged," *i. e.*, a current must be passed through its cells from an external source, in order to produce the chemical decomposition in which the work of storage consists. When this has been done for a sufficient length of time, the two batteries are separated, and the poles of the secondary being connected, a current is immediately set up, having all the properties of, and being able to perform the same work as that from an ordinary galvanic battery. There is no necessity to use the secondary battery at once; it will remain "charged" for a considerable time, and in this fact consist its importance and convenience. The method of charging by a galvanic battery, however, is very expensive, and in consequence no wide use could be made of the storage principle until other means of charging were available. The dynamo machines, to be described in a future chapter, supplied this want, and secondary batteries have consequently come into great request, being specially useful in electric lighting and locomotion.

The possibility of obtaining secondary batteries is really due to polarization. We have already seen (p. 75) how an opposing electromotive force may be set up in an ordinary battery by the deposit of hydrogen on the negative electrode, causing after a time a second positive current flowing in an exactly opposite direction to the first, and so weakening its action. It is this, the polarization current, which is utilized in secondary batteries, and consequently the current in them flows always in the opposite direction to that of the charging battery. Ritter first discovered the principle of secondary batteries, called also accumulators, in 1803, and many years after the eminent French electrician, Gaston Planté, showed how it could be turned to practical use. Faure's storage battery, an improvement on Planté's, is now most generally used.

It is usual and convenient to speak of the conducting wires as though they alone conveyed the current, but theoretically, and as a true explanation of what happens, this is not the case. We have already seen what an important part is played in the phenomena due to static electricity by the insulating medium, and its function in the case of electric currents is equally necessary, for it will easily be understood that though the wires *appear* to convey the current, the surrounding space must take part in the action also, because within such a space the magnetic needle is affected, and other magnetic and electric phenomena occur. We cannot therefore regard the wire so much as a sort of pipe through which something or other is passing, as the centre of a disturbance in the ethereal medium, which disturbance is

propagated along the outside as well as through the wire. It is, in fact, now considered that the energy of an electric current travels entirely through the insulating medium, and not through the wire at all, the function of the latter being to dissipate, not to transmit, the energy it receives. By this dissipation, however, it enables the surrounding medium to continue transmitting more energy, instead of taking up a passive strained condition, such as exists, for instance, in the dielectric layer of a condenser.

This fact, that it is really the space round the wire, and not the wire itself, which conveys the energy of an electric current, explains a phenomenon which was for some time not understood, viz., that an electric current does not instantaneously rise to its full strength when circuit is made, nor instantaneously cease when it is broken. A very slight, but still measurable, delay occurs in both instances, and in the latter the sudden breaking of the circuit will often occasion sparks, showing that the current, unable to stop at once, bursts through the insulating medium interposed with an outbreak of heat and light. Water, which has been several times used as presenting an analogy to electrical phenomena, affords one also here. Water enclosed in a pipe cannot be set in motion suddenly, or if already in motion cannot be suddenly stopped, except by the exertion of a force which is very likely to burst the pipe. With water these two effects are due to inertia, a universal property of matter which can neither start nor stop moving unless force be brought to bear on it. Since an electric current exhibits the same peculiarity, we are naturally led to ask whether that also possesses inertia, and the interest of the question lies in the fact that if it did, electricity would be proved to be a form of matter, however widely different that form might be from those with which we are familiar. But though in the instances cited above (which used formerly to be called "extra-current" effects), electricity appears to possess inertia, in other equally important ways it seems entirely devoid of it. Inertia where it really exists produces well-defined mechanical effects, and examined by any mechanical means an electric current shows no sign of it. The fact is that the effects observed on making and breaking circuit, as well as others of a similar nature, are due not to the inertia of electricity, but to the electro-magnetic inertia of space (or rather of the medium which fills space), and this is quite a different thing. As we have seen, the space surrounding a wire conveying an electric current acquires the property of producing magnetic effects. Such a space must therefore be in a state of magnetization; but it neither acquires nor loses this condition instantaneously, and in consequence causes those phenomena (known as self-induction phenomena), which appear to be due to the inertia of the current itself.

In whatever way an electric current is given rise to, its nature and

effects are essentially the same; and therefore, though one source only, the galvanic battery has yet been described, it will be well to give in the ensuing chapters some more detailed account of the various effects produced. Before doing so, however, a brief mention may be made of what are called *thermo-electric currents*. These arise from setting up a difference of temperature between two junctions formed of two different metals, the effect being more marked when bismuth and antimony are used than with any other metals. Two metals joined for the purpose of giving rise to an electric current through inequality of temperature are called a *pair*, and a number of these pairs may be united so as to form a kind of battery, which is known by the name of a *thermopile*, every alternate junction being either heated or cooled above or below the temperature of the rest of the circuit. When a difference of temperature is set up between two junctions of bismuth and antimony the current flows from bismuth to antimony across the hotter junction, and from antimony to bismuth across the colder, the hotter junction being cooled and the colder warmed during the process, so as to bring them to the same temperature as the rest of the circuit, when the electro-motive force (called *thermo-electro-motive force*) and consequent difference of potential causing the current cease. The currents thus produced are of a low electro-motive force, though some thermopiles have been constructed which generate currents strong enough to depose metals from their solutions, and they have even been made of some practical use in this way. The most usual and important function of the thermopile, however, is to act as an extremely delicate thermometer able to indicate the very smallest changes in temperature, and for this purpose it is invaluable.

CHAPTER II.

CHEMICAL AND PHYSIOLOGICAL EFFECTS OF THE CURRENT.

Difference in the way solid and liquid conductors convey an electric current—Analogy with heat — Electrolytes — Electrolysis — Electrodes — Anions and kathions—Deposition of metals by electrolysis—Electrolysis of water—The voltameter—Free atoms only appear at the electrodes—Gröthuss' hypothesis—Physiological effects of the current—Galvani's experiments—Results of recent experiments—Exciting effect of extraneous currents on living nerves—Difference between the physiological effect of the passage of a galvanic current and a Leyden jar discharge—And of continuous and alternating currents.

Chemical Effects.

AN electric current does not flow in the same way through solid conductors and through liquids. In the former it does not travel *with* the molecules of matter, but in some way *through* them,

whether we picture it doing so, as water filters through sand, or as passing from one molecule to another like heat. Heat itself, however, travels in two ways, by what we call conduction in solids, and by convection in liquids and gases. In conduction there is an increased vibration of the molecules communicated from one to the other; in convection there is an actual double journey of molecules, the hot, light ones rising to the top, and the cold, heavy ones sinking to the bottom. Through most liquid chemical compounds electricity also travels by a kind of convection. There is a double procession of charged atoms, the positive all going one way and the negative the other way, and thus the two kinds of electricity travel with the particles of matter, just as heat does when any liquid is rising in temperature.[1]

In order to produce this double procession of atoms, however, chemical decomposition mnst take place, and all liquids do not undergo this when an electric current is passed through them. It only occurs when the liquid is a conductor, and turpentine as well as most oils are non-conductors. Again, there are liquids which conduct without being decomposed by the process. Mercury and all molten metals belong to this class, but impure water, as well as acid and saline solutions, undergo decomposition whenever a current is passed through them, whether inside or outside the cells of a battery, and they are known in consequence as *electrolytes*. The process of decomposition is called *electrolysis*, a name originally bestowed by Faraday, and abbreviated from electro analysis. The vessel containing a liquid undergoing electrolysis is called an *electrolytic cell*, and the ends of the wires leading from and to the battery, or the strips of metal (usually platinum) to which the wires are connected, and which dip into the liquid, are the *electrodes*. The positive electrode is called the anode, and the negative the kathode.

The atoms set free by decomposition and attracted to the respective electrodes have been already mentioned. Faraday gave them the name of ions, those which appear at the anode being *anions* (the ones which go up), and those which appear at the kathode kathions (the ones which go down). The latter are regarded as being electro-positive because they move with the positive current toward the negative electrode, and the former as electro-negative because they move against the positive current toward the positive electrode. All metallic atoms are kathions—that is, they appear at the negative electrode, and several metals have been discovered through electrolysis by being disengaged from the substance with which they were united and deposited by themselves at the kathode. Potassium is one of these, and was discovered by Sir Humphry Davy.

When very pure water is submitted to electrolysis, there must be

[1] See "Modern Views of Electricity," by Dr. Oliver Lodge, F. R. S., p. 66.

added to it a few drops of sulphuric acid, perfectly pure water appearing to act as a non-conductor. This being done, however, the process of decomposition commences at once, oxygen being evolved at the anode, thereby proving itself to be electro-negative and hydrogen at the kathode, thus showing that it is electro-positive. Nearly twice as much hydrogen is given off as oxygen in consequence of the chemical composition of water, which consists of two parts of hydrogen to one of oxygen. If it is desired to collect the gases thus set free, an apparatus like that shown in Fig. 17, and known as a *voltameter*, must be used. It consists of a vessel containing slightly acidulated water, in which are immersed two strips of platinum connected by wires with the respective poles of a battery. The strips of platinum are the electrodes of the voltameter, and platinum is used because it resists the action of every acid, and is not easily oxidizable. Consequently it does not tend to set up other chemical actions besides that of the current in the voltameter. The two inverted tubes over the platinum strips serve to collect the gases; bubbles appear at the surface of the water with which they are originally filled, and as this happens the level of the water sinks, the upper part of the tube over the anode becoming filled with oxygen, and that over the kathode with hydrogen.[1] The voltameter affords a very direct way of measuring the strength of an electric current, because the amount of chemical action which takes place in a given time is directly proportional to the strength of the current, and within wide limits no other consideration need be taken into account. Copper voltameters are frequently used for practical purposes. Two plates of copper are immersed in a solution of copper sulphate (blue vitriol), and serve as the electrodes, that which is to be the kathode having been first carefully weighed. When the current is passed through the cell, particles of copper are drawn from the solution and deposited on the kathode, while the anode gradually dissolves in the exact proportion necessary to replace the copper taken from the solution. After a given time, the kathode is removed and again weighed, its increase in weight indicating precisely the amount of current that has passed. Though this method of measurement is exceedingly accurate and direct, it can only be adopted in the case of large

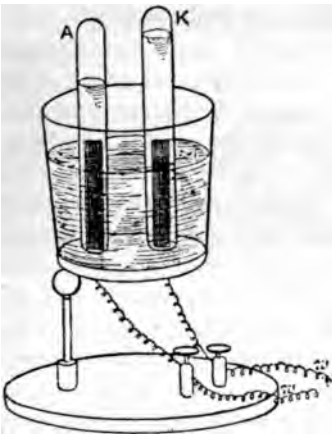

FIG. 17.—Voltameter. A, anode; K, kathode.

[1] The form of voltameter above described, though still frequently seen, is becoming very antiquated, and other better forms have been devised.

currents (such as those used in electric lighting); because in the case of small currents, though the amount of chemical action taking place in a given time is always directly proportional to the current strength, it is too minute to be appreciable for many hours, or perhaps days. Weak currents are therefore measured by their magnetic, not their chemical effects, as will be presently described.

There is one very curious fact regarding electrolysis which must not be left unmentioned, viz., that the separated atoms never make their appearance except at the electrodes, and however many cells they may have to pass through before arriving at their respective destinations, nothing whatever is seen of them on the road. The only explanation which seems to account satisfactorily for this remarkable phenomenon is that known as Gröthuss' hypothesis.[1] He supposed that each molecule of the electrolyte underwent a continual decomposition and recomposition. Thus, taking water as an instance, each molecule of which is composed of one atom of oxygen to two of hydrogen, the first molecule decomposed at the positive electrode sets free one atom of oxygen and two of hydrogen. The latter immediately combine with the oxygen of the second molecule, whose hydrogen is in turn set free, and passes on to combine with the oxygen of the third molecule, which is decomposed and recomposed in like manner, and thus the process continues till the negative electrode is reached, where the last two atoms of hydrogen, having no oxygen to combine with, appear free.

Physiological Effects.

Galvani was the first to draw the attention of the scientific world to these, and he, himself, was accidentally attracted to the subject by observing one day that the legs of some newly killed frogs underwent violent contractions at every discharge of an electrical machine with which he was experimenting. This effect was due to the "return shock," viz., to the frogs' legs having become charged by induction owing to the near neighborhood of the electrical machine, and consequently discharging themselves when it did. Not long afterward Galvani discovered that if a living nerve and muscle are touched by two dissimilar metals in contact, an electric current is set up and the muscle contracts. Subsequently he proved that a single metal would have the same effect, and still later that metal could be dispensed with altogether, and the contraction produced by touching the nerve

[1] Gröthuss' hypothesis has been modified in order to meet the further development of chemical science, and it is now more generally supposed that the molecules and atoms of a liquid being always in motion, the passage of an electric current through them controls the direction of that motion by causing the electro-positive atoms to move towards the kathode, and the electro-negative towards the anode, thus causing the decomposition of the liquid and the appearance of the free atoms.

at two different points with a muscle taken from a living frog. Since his time these experiments have been tried on other animals, warm-blooded[1] as well as cold-blooded, and their scope greatly extended. From these researches it has been ascertained, first, that the power of contracting on the passage of an electric current is a distinguishing property of protoplasm, the physical basis of all animal and vegetable life; secondly, that not only do extraneous currents produce certain defined physiological effects, but also that electric currents exist in the living nerves and muscles of all animals, independent of any external stimulus, and that they cease with death, thus establishing an intimate connection between electricity and vital phenomena. What this connection really is, however, remains unknown, and in any case electricity and life are not, as some people seem to suppose, synonymous.

The effect of extraneous currents on living nerves is invariably to excite them to action. Thus, if a feeble current be passed through the eyeball, a brilliant flash of light is seen, owing to the stimulus given to the optic nerve. If the ear be treated in the same way, musical sounds are heard. A current passed through the tongue causes a peculiar taste, and applied to the ordinary nerves of sensation a pricking and stinging are produced. These effects are mostly momentary, occurring only when the circuit is made or broken, but if this be done frequently and rapidly, an equally frequent and rapid succession of the effects may be produced. Where the current is strong enough to cause contraction, tetanus may ensue if the current be interrupted at frequent and rapidly recurring intervals, owing to one contraction not having time to pass off before another commences. The same effect can be produced by alternating currents (*i. e.*, currents flowing alternately in opposite directions).

A galvanic current does not usually give a shock like a Leyden jar, but it will do so, when circuit is made or broken, if the number of cells in the battery is sufficient to give rise to a high electro-motive force, for it is the difference in this respect between a battery and a Leyden jar which causes the difference in their physiological effects. The battery gives out larger quantities of electricity than the Leyden jar, but the difference of potential between its poles is far less than that between the two coatings of the jar, and consequently the electromotive force of the latter is much the greater. The Leyden jar discharge is like a small stream of water falling from a great height; the battery current like a large stream flowing over a very gently inclined bed, and it will be easily understood how much more likely a "shock" is to occur in the former than in the latter case, especially

[1] The experiments are much more difficult to carry out in the case of warm-blooded animals, because their muscles do not retain vitality so long after the general death of the system. Nevertheless, the same results have been obtained.

as the resistance of the human body is very high and requires considerable electro-motive force to overcome it.

The physiological effects produced by continuous and alternating currents are also different, and the latter are both more painful and more dangerous than the former. A person accidentally touching a wire, conveying a continuous current of an electro-motive force not high enough to give a shock causing unconsciousness, could release himself at will. In the case of an alternating current he could not do so, and would suffer painful muscular contractions while remaining fixed. Moreover, the human body can bear without danger continuous currents of a much higher electro-motive force than it can alternating currents.

CHAPTER III.

MAGNETIC EFFECTS OF THE CURRENT.

First discovery of the deflection of the magnetic needle by the electric current—Œrsted's experiments—Ampère's *memoria technica*—Use of galvanoscope—Of galvanometers—Long and short coil instruments—Astatic galvanometer—Disturbing effect of the earth's magnetism—Compensating magnets—Thomson's mirror galvanometer—Relationship between electric currents and magnetism—Wire conveying current acts as a magnet—Possesses a magnetic field—Magnetic behavior of a single wire loop—Equivalent to magnetic shell of the same dimensions—Application of Ampère's rule—Experiment with metallic ring attached to floating battery—Modern theory of magnetism—Amperian currents—Production of rotation characteristic of magnetism—Tendency of a single magnet pole and an electric current to revolve round each other—Rotation of liquid conductors under magnetic influence.

THE magnetic effects of the current are of the greatest importance, and so long ago as 1803 it was known that an electric current deflects the magnetic needle from its true position, tending to place it at right angles with the conducting wire, so as to make it lie, in fact, *across* the current. No use was made of this discovery, however, nor was it even published, and to Œrsted of Copenhagen belongs the honor of having established the fact by careful experiments and brought it to the notice of the scientific world.

Fig. 18 enables Œrsted's experiments to be understood. A magnetic needle is placed between two wires lying in the magnetic meridian. One is above and one below the needle, and both are able to be connected with a battery. If a current is made to pass from North to South through the *upper* wire, *i. e.*, above the needle, the North-seeking pole of the needle is immediately deflected to the

East. If it passes from South to North through the same wire, as in the figure, the deflection of the North-seeking pole is to the West. These deflections are exactly reversed if the current passes through the wire *below* the needle. The North-seeking pole is then deflected to the East when the current flows from South to North, and to the West when it flows from North to South. Ampère has given a very curious *memoria technica* to facilitate the remembrance of the various deflections. Suppose a man swimming in the conducting wire *with* the current and always turning his face toward the needle,[1] all four deflections will then take place toward his left hand, so that keeping this rule in mind the following principle will be understood: "In the directive influence of currents on magnets the North-seeking pole is always deflected to the left of the current."

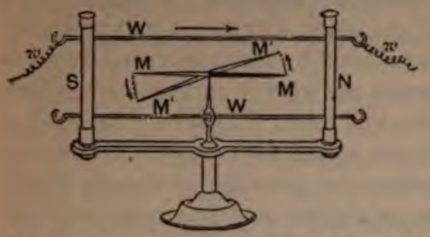

FIG. 18.—W W, wires fixed in the magnetic meridian; M M, magnetic needle lying in its normal position; M' M', the same deflected by a current passing from south to north above it, as indicated by the arrow.

The stronger is the current, the nearer does the deflection of the needle approach to a complete right angle with the conducting wire, but it never entirely reaches this, the directive action of the current being opposed to that of the earth, which tends to keep the needle in the magnetic meridian, so that the position of the needle must always depend on the relative strength of these two forces.

The deflections of the magnetic needle afford a means of indicating the direction and strength of an electric current. An instrument constructed for the former of these two purposes is called a galvanoscope. The simplest of all is made by bending the conducting wire into a rectangular form, so that the current passes in one direction below the needle and in the opposite direction above it, thus acting on it with a double strength, because, as we have already seen, a current from North to South below the needle deflects the North-seeking pole in the same direction as a current from South to North above it.

This apparatus, even when improved by having a great many turns of wire round the needle instead of one, so as to increase the effect of the current,[2] cannot, however, do more than roughly indicate whether it is strong or weak, or which of two currents is stronger. It cannot

[1] To do this when the current passes *below* the needle he would, of course, have to be lying on his back.

[2] Up to a certain limit, the magnetizing effect of the current is increased with every extra turn of the wire, but since resistance is also proportionately increased (owing to the greater length of wire which the current has to traverse), it may at length become so high as completely to counteract the strengthening effect of the coils.

correctly measure the strength of a current relatively to other currents. Yet to know this is of the utmost importance in practical work, and for this purpose, therefore, *galvanometers* are employed. It is unnecessary to enter into any detailed explanation of them. The same instrument will not suit all purposes, but every galvanometer must have a magnetic needle surrounded by a coil of carefully insulated wire. In long coil instruments the wire is turned many, often thousands of times, and is very fine and thin. These instruments are extremely sensitive and are specially suited for very delicate experiments, and to include in circuits where the resistance is already great. In short coil instruments the wire is thicker and has comparatively but few turns, and these should be used in circuits of low resistance. Some definite controlling force is needful in every galvanometer. It may be that of the earth, or of some fixed permanent magnet. In this case the magnet has to be placed at a considerable distance from the needle, so that the latter may be in a field of practically uniform strength. This condition is always perfectly fulfilled where the con-

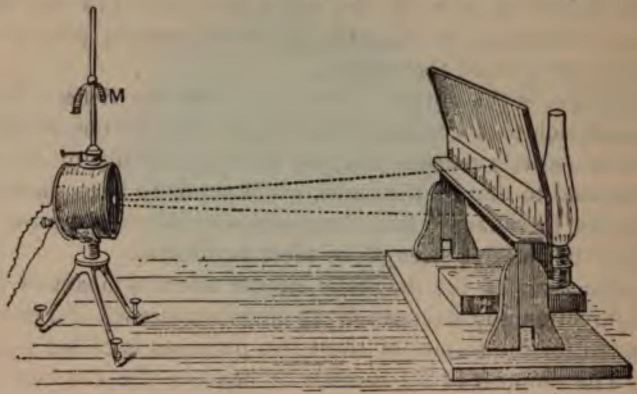

FIG. 19.—Thomson's Mirror Galvanometer.

trolling force is that of the earth's magnetism; but in the case of very sensitive galvanometers, where it is necessary that the controlling force should be very weak, means often have to be employed to obviate the effect of the earth's magnetism. To fulfill this purpose in some galvanometers, use is made of an *astatic pair* of needles, *i. e.*, two needles of equal magnetic strength and size poised carefully one over the other in reversed positions, so that the opposite poles are confronted, each needle being surrounded by a separate coil of wire, the current through one coil being sent in the opposite direction to that through the other. The result of this arrangement is to neutralize the effect of the earth's magnetism on the needles through their mutual reaction, and a very high degree of sensibility can thus be attained. An astatic galvanometer of very great delicacy is Sir

William Thomson's mirror galvanometer, till recently used for signaling through submarine cables. Its general appearance is given in Fig. 19. The readings are made by means of a very small light mirror of silvered glass fastened to the magnetic needle. When the instrument is in use, a beam of light is made to fall on the mirror from a lamp, and is reflected with every movement of the needle to a different point on the scale placed opposite, thus indicating exactly the amount of deflection. The curved metallic piece M is a controlling magnet.

In order that a galvanometer should be able to perform its object, viz., afford a means of accurately measuring the strength of currents, it is necessary in every instrument to ascertain the exact deflections of the needle corresponding to definite currents. When this is known, a basis of comparison is provided, because the same instrument under the same conditions will always show the same deflection for the same current. When the experiments and calculations necessary to determine the deflections of the needle of any particular galvanometer for various currents have been gone through, it is said to be *calibrated.* It is calibrated *absolutely* if the actual currents in ampères producing the different deflections are known; and *relatively* if only the connection between these deflections and the relative current-strengths is determined.

The marked effects produced by electric currents on the magnetic needle, give a very clear indication that there is some close relationship between such currents and magnetism. A yet more striking proof of this is, however, afforded by the fact that an electric current itself possesses magnetic properties. The simplest way of proving this is by passing a battery current through a piece of straight copper wire, and then approaching iron filings to it. The filings at once set themselves at right angles to the wire and cling round it, continuing to do so as long as the current passes; thus showing that the wire has acquired for the time being the power of attracting magnetic substances, if they come within its range of influence. In fact, it produces a magnetic field.

If, instead of a straight wire, a wire curved into a single loop, as in Fig. 20, be used, and the current passed through that, the magnetic field is now enclosed within the loop and coincides with its edges. In fact, such an arrangement as this is exactly like a magnetic shell, which we saw (p. 64) was a magnetized sheet of metal, one surface being entirely North-seeking and the other entirely South-seeking. If the observer be so placed as to look down on the loop, and the current be flowing through it from right to left as shown in the figure, *i. e.*, in the same direction as the hands of a watch move, the upper surface of the

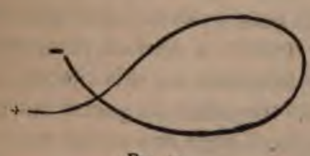

FIG. 20.

loop and the space enclosed will be South-seeking. Referring to Ampère's rule, we should find that a man swimming with the current and facing towards the centre of the loop would be obliged to keep his left side *down*, consequently the North-seeking pole of a magnet would turn itself downward through such a loop. If, however, the current were flowing from left to right, *i. e.*, in the opposite direction to that in which the hands of a watch move, the upper surface of the loop and the enclosed space would be North-seeking. In swimming with the current and facing toward the centre, Ampère's man would have to keep his left side *up*. Transforming him into a magnet, we should find the North-seeking pole urged upward.

A curious and interesting experiment may be made to illustrate these facts by means of De la Rive's floating battery, which consists of a strip of zinc and a strip of copper passed through a large cork and set floating in a vessel containing acidulated water. If the metallic strips be connected by a stout copper ring, and a bar magnet held toward it, the ring will be attracted or repelled according to the pole presented. If the North-seeking pole of the magnet be held toward the South-seeking face of the ring, the latter will be attracted, and will thread itself on to the magnet quite up to the centre. If the South-seeking pole be presented to the South-seeking face of the ring, the latter will be repelled, and if nevertheless forced to pass on to the magnet, will, as soon as let go, rapidly unthread itself, turn round so as to present its North-seeking face, and then re-thread itself up to the centre of the magnet as before. This is exactly how a magnetic shell would behave under similar circumstances, supposing that a hole were pierced through its centre to allow of its passing on to the magnet; and in fact every closed voltaic circuit (of which the loop or ring we have been considering is an instance) is in all respects equivalent to a magnetic shell of the same dimensions. It attracts and repels according to the same laws, and moreover, if placed itself in a magnetic field, it experiences just the same influence as the shell would do. We have therefore here a most striking illustration of the close relationship between magnetism and current electricity, and it will hardly surprise the reader to hear that according to the most modern theory they are in fact identical, only in the latter the flow takes place from one point to another, and may be compared to that of a river, whereas in magnetism the movement is one of rotation, like the motion of water in a whirlpool. According to this theory, a magnet (which consists of a number of infinitesimal magnets) has a separate current of electricity circulating round each one of its molecules, and these currents when a perfect state of magnetization is reached, and all the molecules are set end to end, are parallel to each other. Without entering into details, which might be found tedious and complicated, it is sufficient to state that their effect on external

space and objects is exactly the same as though a current were circulating round the outside of the magnet. This is because only the currents belonging to the surface molecules are free to act externally at all, those in the interior being neutralized by their action on each other. The theory of these molecular currents is due to Ampère, and they are called by his name, amperian currents. It is the case that they do satisfactorily explain magnetic phenomena, but it is not probable that they are called into existence by the act of magnetization. They are most likely already present in magnetic, and in fact in all substances. Magnetization merely renders their presence sensible externally, by setting them in a parallel direction through altering the position of the molecules. Those substances, therefore, whose internal structure does not lend itself to such a change, or only with great difficulty, are not capable of magnetization in the ordinary sense of the term. It must be remembered, however, that when a sufficiently powerful external force is exerted, all substances do feebly show signs either of magnetic or dia-magnetic phenomena, and the latter also are explicable by means of Ampère's theory.

That the production of rotation is a characteristic of magnetism can be very easily proved. One simple and striking experiment is described by Dr. Oliver Lodge in his "Modern Views of Electricity."[1] A long piece of gold thread is suspended in close proximity to an upright bar magnet, and a current passed through the thread. The latter immediately begins to coil itself round the magnet, half of it round the North-seeking pole, and the other half round the South-seeking pole, in such a manner that the two halves form a common spiral. If the gold thread were exchanged for a stiff wire, and a flexible magnet used, the magnet would then coil itself round the wire. In fact, it is proved that a single magnet pole would, if free to move, continually revolve round an electric current, and that an electric current would in the same way revolve round a magnet pole. As we know, however, it is impossible to obtain a magnet with one pole, it must always have two, and therefore a rigid magnet and a rigid conductor cannot possibly show this movement of rotation. All they can accomplish is to place themselves at right angles to each other, as we have seen the magnetic needle invariably tends to do when placed over, under, or near a wire through which an electric current is passing.

Liquid as well as solid conductors can be made to rotate under the influence of magnetism. If a vessel containing acidulated water be placed over a powerful bar magnet and electrodes immersed in it, one at the centre of the vessel and one at the edge, the liquid will begin to rotate, and that so forcibly as very likely to cause it to splash over the sides of the vessel when a current is sent through the liquid.

[1] P. 135.

CHAPTER IV.

ELECTRO-MAGNETS.

Definition of the term—Discovery of the way of making electro-magnets—Solenoids—Manner of insulating the coils of an electro-magnet—Shapes of electro-magnets—Way of widening the coils of a horse-shoe electro-magnet—Position of North-seeking and South-seeking poles—Formation of consequent poles—Core of an electro-magnet takes time to become magnetized—Magnetic strength of electro-magnets—Coils with a number of turns only appropriate in a circuit of high resistance—Kind of metal used for the coils a matter of indifference—Reason of the importance of the iron core.

FROM the observations made at the close of the preceding chapter it will be seen that all magnets may perhaps be *electro-magnets*, because without electricity it is probable that neither magnets nor magnetism would exist. The term is not used, however, in this general sense, but refers exclusively to bars of iron or steel made into magnets by being enclosed in a spiral coil of wire through which an electric current is caused to pass. Steel treated in this way becomes permanently magnetized, but a bar of soft iron only retains the whole of its magnetism while the current lasts. Consequently, this being a great practical convenience, it is soft iron which is almost invariably used for the "core," as it is called, of electro-magnets. The amount of magnetism which the core retains when the current ceases is so faint that it seems hardly worth noticing. Nevertheless, as we shall hereafter find, this feeble "residual magnetism" has been made to yield the most important practical results, and it must not therefore go unnoticed.

The principle of electro-magnets was known as far back as 1820, when Arago and Sir Humphry Davy independently discovered that a

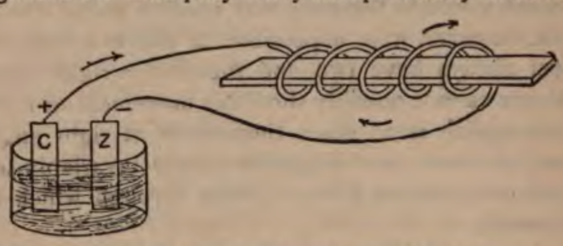

FIG. 21.—Soft iron bar, magnetized by being placed within a wire spiral conveying the current from a single cell.

bar of iron or steel could be magnetized, as shown in Fig. 21, by being enclosed in a wire spiral through which an electric current was caused to circulate. The first practical electro-magnet was, however, made and exhibited by William Sturgeon in 1825, and he is therefore justly regarded as the inventor of this most useful and important

appliance of electro-magnetism. Though a soft iron bar is always used in electro-magnets, it is not indispensable. A wire spiral without a core will also acquire magnetic properties, though never to such an intense degree. It is then called a solenoid, and behaves like a bar magnet, setting itself in the magnetic meridian if freely suspended, and having, of course, a North-seeking and South-seeking pole, which have the power of attracting and repelling other magnetic poles, and of attracting and being attracted by magnetic substances. Fig. 22 represents a solenoid arranged for suspension.

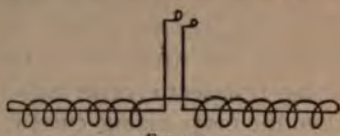
FIG. 22.

In electro-magnets care must be taken that each coil of the wire is separated from the next and from the iron core, for if contact takes place at any point, the current passes from one coil to another instead of round each coil, and its effect is thus weakened; for as has been already stated in a previous chapter, the magnetizing effect of the current is increased by increasing the number of coils in the wire, at least up to a certain point.[1] The insulation of the coils from each other and from the core is effected by covering them with silk or cotton thread, the latter dipped in melted paraffin wax, or with a thin coating of gutta-percha, and they are wrapped as closely round the core as can be managed without weakening the insulation. This is done to avoid the increase in resistance, which the greater length of wire required for wide coils would give rise to. The ends of the core always protrude beyond the coils.

Electro-magnets, like permanent magnets, may be of any shape, but the most usual are the bar and the horse-shoe. Fig. 23 represents the latter in which two coils of wire are used, leaving the central part of the magnet bare. In order that with this arrangement one pole may be North-seeking and one South-seeking, the wire must be wound so that if the magnet were straightened out the coils would all follow the same direction. At whichever end the current enters the coils, the North-seeking pole is always that where it flows round them in the opposite direction to the way in which the hands of a watch move, and the South-seeking pole that at which it flows in the same direction.

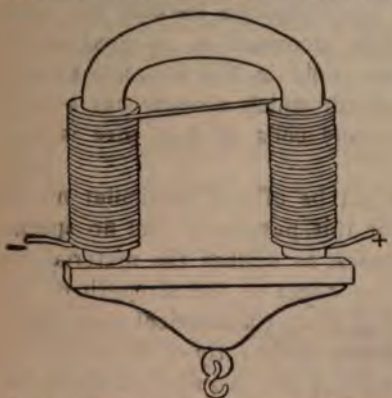

FIG. 23.—Horse-shoe Electro-magnet with keeper and hook for suspending weights.

[1] See p. 85, note.

If the wire is coiled irregularly, at every change of direction a consequent pole is formed, just as happens in the case of an irregularly magnetized ordinary magnet.

The core of an electro-magnet takes time to become magnetized, partly because an electric current does not (as has already been stated, p. 78) attain to its full strength at once, and partly because of the transient inverse induction currents started in the core itself, when the magnetizing current commences to flow through the coils (see p. 98).

Augmenting the strength of the magnetizing current, and augmenting the number of convolutions in the coil of an electro-magnet, alike increase the magnetizing power of the latter. In fact, for low intensities of magnetization the amount of magnetism is approximately proportional to the product of the current into the number of convolutions of wire, but after a certain point is reached this ceases to be true, because as the magnetism becomes stronger and stronger it increases less and less slowly with the product, so that beyond a certain point a very large increase in the product is necessary in order to give rise to a small increase in the magnetism. Nevertheless, as this small increase does take place, it cannot, strictly speaking, be said that such a thing as saturation exists in the case of an electro-magnet. Other considerations beside the intensity of the magnetizing force to which it is subjected, affect the amount of magnetism which the core of an electro-magnet can acquire. The quality of iron of which the core is made, its shape, length and thickness, are all of importance. It must be remembered also, that since the resistance encountered by the magnetizing current increases with the number of coils, it would be a mistake to include an electro-magnet with a great many coils in a circuit of otherwise low resistance, because the total resistance would be thereby so much increased as to weaken the current. A few turns of stout wire would in this instance answer the purpose better, whereas in a circuit which already has a high resistance an electro-magnet with many coils of fine wire is preferable.

The wire used in the coils need not be of any particular metal. Copper is very often chosen, but for this purpose it has no special merit except its small specific resistance, as neither the material nor the thickness of the wire produces any effect on the strength of the electro-magnet. The important thing is that a sufficient quantity of electricity per second should be carried sufficiently often round the iron core to produce a magnetic field of the required intensity between it and them. For this purpose, when stout wire is used, a few turns will suffice, because in this case a considerable quantity of electricity will be carried round the core of the electro-magnet in one convolution, whereas in the case of fine wire a great many turns are

necessary, since one convolution only suffices to carry a small quantity of electricity round the core.

It is of interest to know why the introduction of a soft iron core into a wire spiral should so greatly increase its magnetic strength. The explanation is to be found in the fact of the alteration that takes place in the direction of the lines of force. These in an ordinary steel bar magnet run from end to end, and round outside from one pole to another (see Fig. 11, p. 65). In a solenoid (without a core) very few of them do this; they nearly all remain as closed curves round the wire, each separate coil of which acts like a magnetic shell. When the core is introduced, on account of the high inductive power of iron, most of the lines of force in the solenoid are compelled to alter their direction and follow that of those existing in the iron itself, which run through the length of the iron and back from pole to pole, as in the case of the steel magnet already described. Consequently the strength of the poles, being thus reinforced, is very greatly increased.

CHAPTER V.

ACTIONS OF CURRENTS UPON CURRENTS—INDUCTION CURRENTS.

Mechanical reaction of conductors which are conveying electric currents—Due to attraction and repulsion between the currents—Ampère's laws—Ampère's table—Further laws—Induction of one current by another—Primary and secondary coils—Direct and inverse currents—Induction of currents by magnets—Self-induction—Its effect on the primary current—Contact-breakers—High electro-motive force of induction coils—Ruhmkorff's coil—Sparks from induction coils—The aureole—Effects obtained by means of Geissler's tubes—Effect of a magnet on luminous discharge through rarefied air—Induction currents in solid masses of metal—Lenz's law—Experiment with metal disc suspended between the poles of two electro-magnets—Currents of the higher order.

HITHERTO our observations have been confined to the magnetizing effects of an electric current, but another equally important fact demands attenticn. It is that electric currents act and re-act on each other, causing movements in the conductors conveying them. These movements are due to the mutual attractions and repulsions between the currents, for flowing electricity, like electricity at rest, exhibits these phenomena, though they are governed by entirely different laws, first discovered and studied by Ampère.

He found—

I. That currents conveyed by parallel wires attract each other if following the same, and repel each othe if following different directions.

II. That currents conveyed by wires which are inclined to each other at any angle, are mutually attracted if both flow toward or both flow from the apex of the angle, and mutually repelled if one flows toward and one from it.

Ampère devised an apparatus known as Ampère's table for observing the actions of currents on each other. It consists of a stand with double supports, upon which wire conductors of different shapes may be suspended in such a way as to allow them to rotate, and at the same time connected to a battery, so that a current may be passed through them and the behavior of the various portions of wire with regard to each other be observed. By the help of this apparatus Ampère showed that two parts of a circuit in whatever relative position they may be, experience a force tending to set them in such a direction as to enable the currents they convey to flow in the same path ; also that a wire doubled back on itself, so that the current takes a return path close to the one it was following before, does not exert any external force ; and further, that a zigzag wire exhibits the same magnetic influence over a not very near portion of the circuit as a straight one. Ampère also demonstrated that a conductor never experiences a force tending to move it in the direction of its own length, because the attractions and repulsions between currents always act at right angles to the currents themselves, tending therefore to make them revolve round each other.

Since a mutual action exists between currents and currents and between currents and magnets, it is not surprising that under certain circumstances one current should be able to induce, *i. e.*, bring into existence, another, and that magnets should also possess the same power. In their case it is exerted whenever a magnet is moved about in the neighborhood of a closed circuit, or when the circuit itself is moved in or across a magnetic field. In the case of currents, a current *whose strength is changing* induces a secondary current in any conductor near it ; and currents produced in either of these ways are said to be caused by electro-magnetic induction, and are called *induction currents.* Their discovery is due to Faraday.

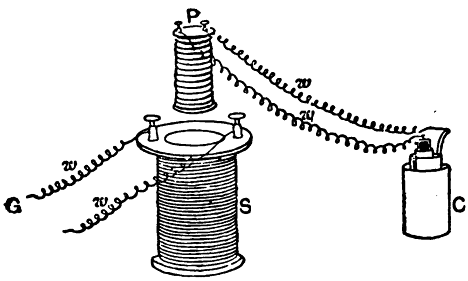

FIG. 24.—P, primary coil ; S, secondary coil ; C, battery cell ; G, position of galvanometer.

In order to show the induction of currents by currents, two coils of wire are necessary, of which one is usually large enough to allow of the other being inserted into its hollow. This is merely for convenience' sake, however, as the relative size of the two coils is quite

immaterial so far as the generation of induction currents is concerned. The small coil, which is called the *primary*, and is made of stoutish wire with few turns, is connected to a battery; and the large coil, in which the wire is fine and often coiled many thousand times, is called the *secondary*,[1] and connected to a long coil galvanometer, as shown in Fig. 24.

When the battery current is passed through the primary coil and the latter inserted into the hollow of the secondary, the galvanometer needle indicates a momentary current in the *opposite* direction to that in the primary coil, and the same effect is produced if the current starts in the primary while it is lying in the hollow of the secondary. When the former is withdrawn, or when circuit is broken while it is lying in the hollow of the secondary, another current is indicated in the latter in the *same* direction as that in the primary. This is called a *direct current*, and the former an *inverse current*. Inverse currents are produced in the secondary coil whenever a current in the primary coil begins, increases in strength, or approaches nearer; direct currents in the secondary coil occur whenever that in the primary ends, decreases in strength, or recedes. Neither inverse nor direct currents ever occur except when a current in the primary starts or stops, or when one of the coils is moved (for moving the secondary nearer to or farther from the primary produces the same effect as moving the primary itself), and their duration is only momentary.

To show the induction of currents by magnets, it is merely necessary to replace the primary coil of Fig. 24 by a bar magnet. It will be found that whenever the magnet is inserted in, or approached to the hollow of the remaining coil, a current is produced in one direction, and a current in the opposite direction whenever the magnet is taken out or withdrawn to a greater distance.

Beside the induction of one current by another, there is also the induction of a current on itself, called more shortly *self-induction*, to which brief reference was made in a former chapter. By it is really meant, that if two portions of the same circuit are placed side by side, the sudden commencement or cessation of a current in one portion tends to induce a momentary current in the other, just as if the two portions belonged to separate circuits. Thus, suppose we have a wire doubled back on itself, as in Fig. 25, and the primary current flowing in the direction indicated by the single barbed arrows, at the commencement of such a current there would be a tendency to induce a momentary inverse current flowing in the direction of the double

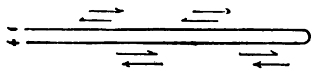

FIG. 25.—Diagram to illustrate Self-induction.

[1] The result of having stout wire with few turns in the primary, and fine wire with many turns in the secondary coil, is that a large current of low electro-motive force induces a comparatively small current of very high electro-motive force.

barbed arrows; and at the cessation of the primary current a tendency to induce a momentary direct current, flowing, of course, with the single barbed arrows.[1] This induction has the effect of weakening a current at its start (thus delaying its growing to its full value), and strengthening it at its cessation, which is thus retarded. In fact, since the induction of the current in one part of a circuit takes place on another part of the same circuit across the intervening medium, energy is transferred to the latter while the circuit is closed, and the current remains constant in strength, but is given back to the circuit again to produce the "extra current" on the stoppage of the main current. This is the reason why sparks are obtained on breaking circuit. They are much more brilliant if a coil of many turns be included in the circuit; and if the coil contains a soft iron core, this again increases the sparking power. There are various automatic contrivances called contact-breakers, or interrupters, used for making and breaking circuit with regularity and rapidity, but a detailed description of them is unnecessary for the present purpose.

Induction currents have an enormously high electro-motive force, and very striking effects can consequently be produced by them. These are shown in a marked and powerful way by the induction coil or inductorium, often known under the name of *Ruhmkorff's coil*, as that inventor did much to perfect it. Its most important parts are, of course, a primary and secondary coil, placed one within the other, and the former connected with a battery, and containing a core of straight soft iron wires. Under the coils there is a condenser, which is placed within a flat wooden box and consists of sheets of tinfoil, separated by sheets of paraffined paper, each alternate piece of tinfoil being electrically connected, so that the whole set forms two series corresponding to the inner and outer coatings of a Leyden jar. A contact-breaker and a commutator or key, whose use is to reverse the direction of the battery current whenever the operator chooses, complete the apparatus. The wires from the primary coil are, as has already been said, connected with the terminals of a battery, and those from the secondary with the condenser, the use of this latter arrangement being that the spark on breaking circuit may be mitigated by lessening the amount of extra current in the primary coil, some of the electricity flowing into the condenser, instead of to the point where the break is made.

The sparks from an induction coil are extremely powerful, and often attain a great length. From eighteen to twenty inches is not at all unusual with a large instrument, and sparks a metre long have been obtained from some of its most modern forms. These sparks

[1] In a simple circuit, such as that represented in the figure, there would be very little self-induction, however, whereas in a circuit coiled many times on itself, there would be a great deal.

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